NOV 26 1956

NINETY-EIGHTH YEAR

AMERICAN Gas Journal

Only Magazine Published Exclusively for the Gas Utility Industry

Handbook Issue

NOV 27 1956

TECHNOLOGY

UTILIZATION

EQUIPMENT

OPERATIONS

NOVEMBER 15, 1956

MUELLER®

Sizes ¾"and 1"
Pressures to 1200 p.s.i.

No-Blo® Steel Valve. For high pressure service lines. Machined from steel forging. Available with threaded or welding inlets and outlets. "O" rings around stem and in cap prevent leakage to the outside. Metal to metal line contact of stem and seat assures gas-tight shut-off. The No-Blo Steel Valve can be completely reconditioned under full line pressure without escape of gas by using the Mueller E-4 Drilling Machine and gate valve. Easily operated from above ground through curb box.

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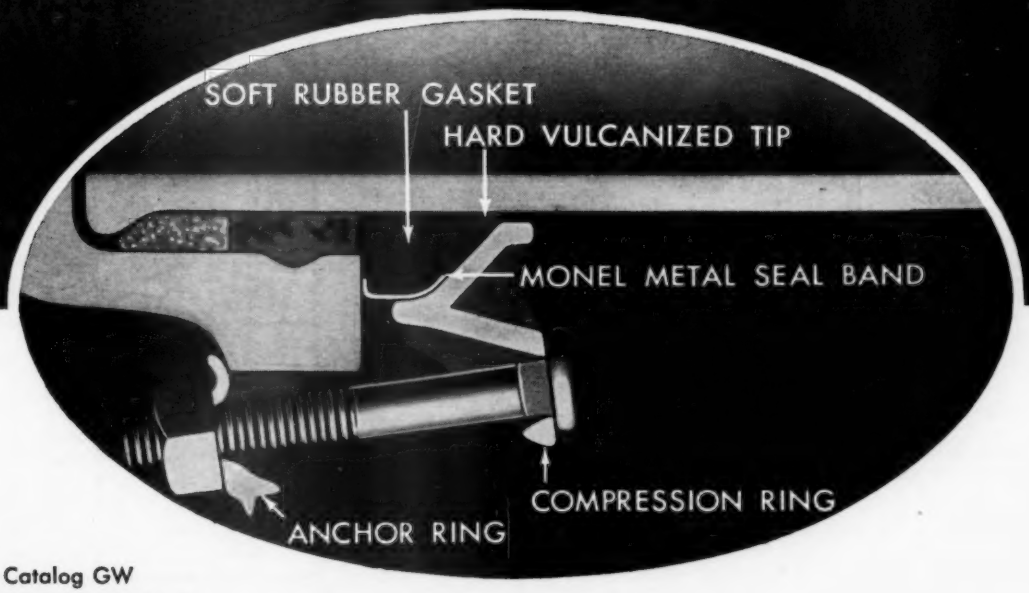

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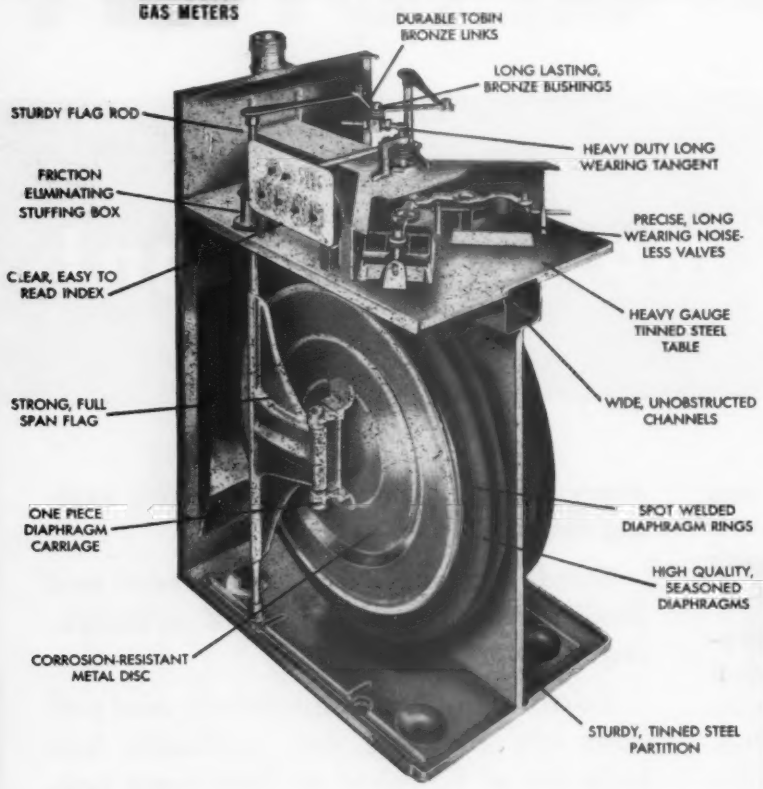
SUPERIOR GAS METERS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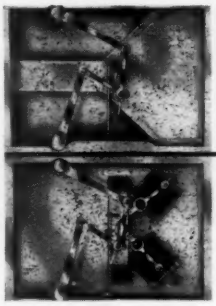
SPOT WELDED DIAPHRAGM RINGS
HIGH QUALITY, SEASONED DIAPHRAGMS
CORROSION-RESISTANT METAL DISC
STURDY, TINNED STEEL PARTITION



CLOSED TOP CONSTRUCTION: Tinned steelplate mounting stand protects valves and working parts from gums, dirt and other foreign matter commonly found in certain gas conditions.

OPEN TOP CONSTRUCTION: Excellent for clean gas conditions. Valves and moving parts immediately accessible under casing cover. Permits easier maintenance, faster servicing, quicker "O.K.'s."

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Write today for Bulletin 1100-H.

METER SPECIFICATIONS

	Size	Rated Capacity in Cu. Ft. Per Hr.	Pipe Size–Inches	Net Weight Pounds	Width Center to Center of Pipe–In.	Height to Top of Pipes Inches	Proving Head–Feet	Revolutions Per Foot
TYPE "A"	5	210	½	15½	11⅜	16⅜	2	6
	5	250	½	15½	11⅜	16⅜	2	6
	5	300	¾	15½	11⅜	16⅜	2	6
	10	400	¾	23½	13⅜	18½	5	3⅗
	20	600	1	40½	16⅜	22	5	2
	30	900	1¼	47½	18¼	26¼	5	1⅗
	60	1500	1½	118	25¼	33⅛	20	½
TYPE "B"	5	150	½	15½	11⅜	16⅜	2	6
	10	300	¾	23½	13⅜	18½	5	3⅗
	20	450	1	34	16⅜	22	5	2⅕
	30	600	1¼	47½	18¼	26¼	5	1⅗
	60	1300	1½	117	24	31⅜	10	⅗
TYPE "C"	6	600	1¼	35	14⅜	19¾	10	1⅘
	11	1100	2	68	19⅞	27¾	10	⅘
	25	2500	2½	156	25⅜	34	20	7/20
	40	4000	3	215	29¼	38½	50	⅕
	60	6000	4	400	36	45¼	100	1/10
	75	7500	4	400	36	45¼	100	1/10
TYPE "T"	2	80	⅓	8.3	7¾	12⅝	1	20
	2	100	⅓	8.3	7¾	12⅝	1	20
	2	140	⅓	8.3	7¾	12⅝	1	20
	5	150	½	15½	11⅜	16⅜	2	6
	5	210	½	15½	11⅜	16⅜	2	6
	5	250	½	15½	11⅜	16⅜	2	6
	5	300	¾	15½	11⅜	16⅜	2	6
	10	300	¾	23½	13⅜	18½	5	3⅗
	10	425	¾	23½	13⅜	18½	5	3⅗

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NINETY-EIGHTH YEAR

AMERICAN Gas Journal

GAS TECHNOLOGY — OPERATIONS — EQUIPMENT — MANAGEMENT — UTILIZATION

VOLUME 183 **NOVEMBER 15, 1956** *NUMBER 12*

CONTENTS

GAS HANDBOOK ISSUE

Index to Technical Data and Information 10
Weights and Measures, Conversion Tables 17
Deviation of Gases from Ideal Gas Laws 25
Horsepower, Torque, and Electric Motor Calculations 35
Compressing Air and Gas 36
ASA Code for Gas Distribution and Transmission Piping 38
Pipe Specifications, Cast Iron and Steel 49
Gas Flow Formulas 52
Gas Service Design 55
Corrosion Control Methods 60
Guide to Protective Coatings for Pipe 62
Determining Regulator Capacities 65
How to Prevent Regulator Freezing 68
How to Size Meters for Residential and Small Commercial Loads 69
High Pressure Measurement with PD Meters 70
Proof Testing Gas Meters for Accuracy 71
Design of Large Volume Gas Measurement Facilities 72
How to Compute Flow of Gas Through Orifice Meters 76
Drying Agents and Dehydration Processes 91
Odorization of Natural Gas 92
Properties of Odorants for Natural Gas 94
Interchangeability of Various Gases 100
Rapid Survey Method To Determine Gas Requirements and Costs 114
Degree Day Tables 118
Industrial Heating Operations 119
Interest Tables 126
Unaccounted-for Gas Problems and Causes 129

Advertisers' Index 6

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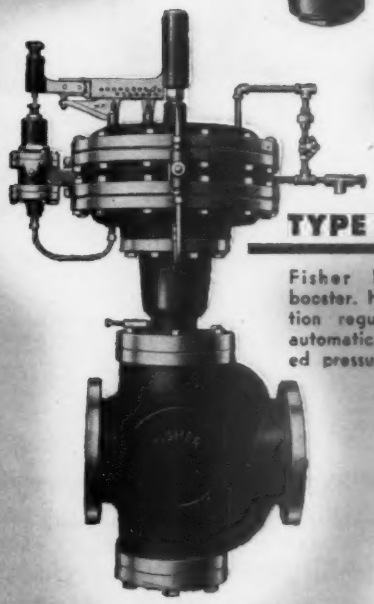

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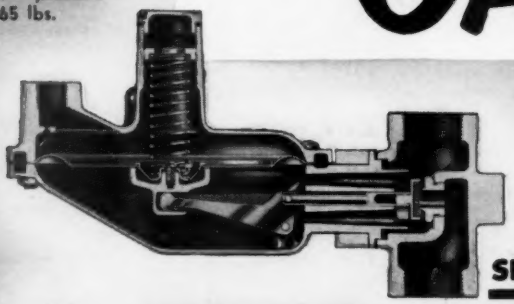

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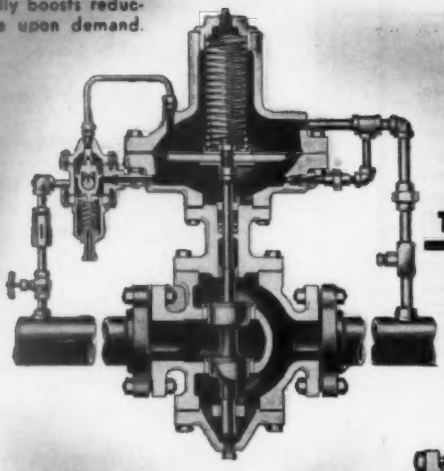
Standard gas service regulator with or without integral relief valve, bug-proof vents. Also available with safety shut-off feature. Sizes ¾", 1", 1¼" and 1½".



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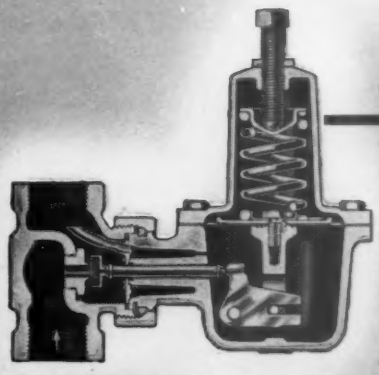
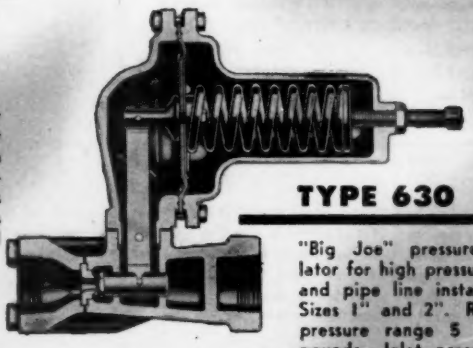
Pilot loaded, pressure balanced high pressure station regulator, ideal as town and border station regulator for dependability and stable metering. Pressures to 600 psi inlet, 250 psi outlet. Sizes 2" to 10", iron or steel.



TYPE 620

Pounds to pounds regulator especially suited for first stage reduction on farm taps. Also designed for industrial gas applications where good regulation is required. Sizes ¾", 1" and 1¼".



TYPE 630

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TYPE 4100U-657

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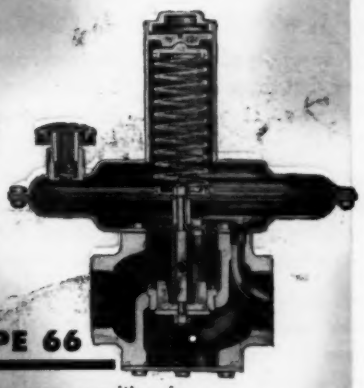
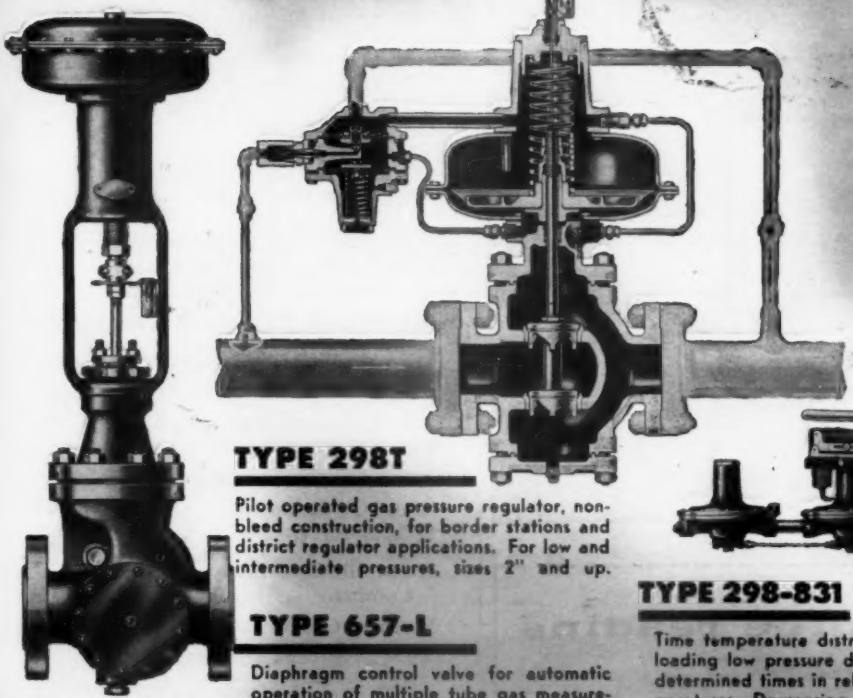


TYPE 66

Low pressure sensitive industrial regulator for inlet pressures up to 5 lbs. Reduced pressure "WC to 1 lb. Sizes 2", 3", 4".



TYPE 298T

Pilot operated gas pressure regulator, non-bleed construction, for border stations and district regulator applications. For low and intermediate pressures, sizes 2" and up.

TYPE 657-L

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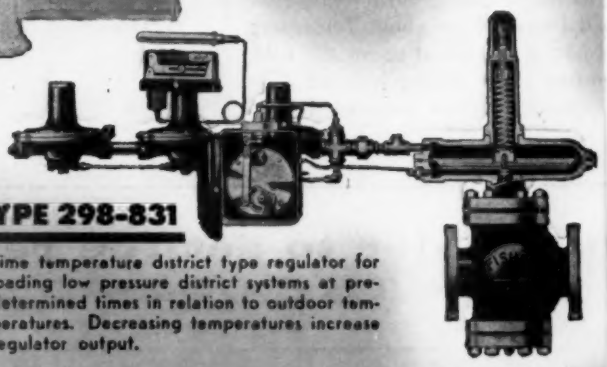

TYPE 298-831

Time temperature district type regulator for loading low pressure district systems at predetermined times in relation to outdoor temperatures. Decreasing temperatures increase regulator output.

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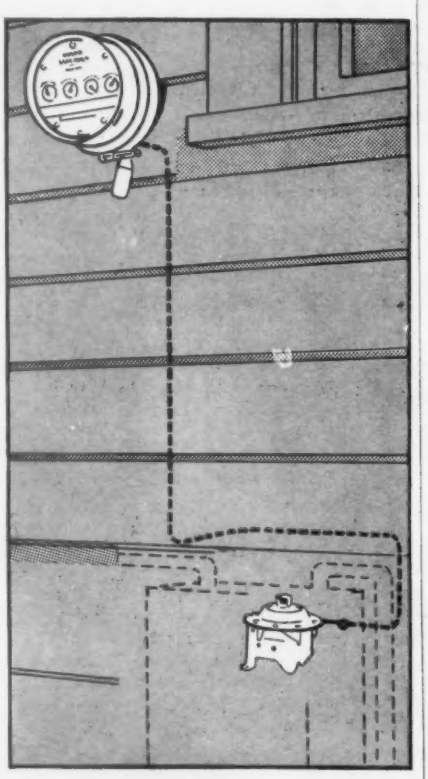
We wrote everything down we thought you'd like to know about Telemeters and had it published under the title, "Outdoor meter reading is here..." or Bulletin 302. We've reserved a copy for you, so write for it today.



it's easier to get the reading ON THE OUTSIDE!

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SPRINGFIELD, ILLINOIS

GT56-1

Advertisers Index

American Liquid Gas Company ... 135
American Meter Company ... 7
American Telephone & Telegraph ... 140

Cleveland Trencher Company, The ... 108
Chaplin-Fulton Manufacturing Company ... 9
Connelly, Inc. ... 141

Drake & Townsend, Inc. ... 141
Dresser Industries, Inc. ... 110, 136-137
Dresser Manufacturing Division ... 110

Fisher Governor Company ... 4-5

Gas Machinery Company, The ... 143
Gas Purifying Materials Company ... 144

H & M Pipe Beveling Machine Company ... 14
Hays Manufacturing Company ... 131
Heath Survey Consultants, Inc. ... 133
Holan, J. H., Corporation ... 13
Hydrauger Corporation, Ltd. ... 129

Lancaster Meter Parts Co. ... 130
Lone Star Steel Company ... 144

McDonald, A. Y., Mfg. Co. ... 12
Mine Safety Appliances Company ... 139
Mueller Co. ... Inside Front Cover

North American Utility & Construction Corp. ... 142

Oronite Chemical Company ... 16

Peerless Manufacturing Co. ... 132
Posey Iron Works, Inc. ... 112

Reed Manufacturing Company ... 129
Reliance Regulator Division, American Meter Company ... 8
Reynolds Gas Regulator Company ... 138

Safety Gas Main Stopper Co., Inc. ... 144
Sangamo Electric Company ... 6
Selas Corporation of America ... 15
Sherman Products, Inc. ... Inside Back Cover
Skelly Oil Company ... 129
Skinner, M. B., Co. ... 1
Somerville Construction Company ... 141
Southern Cross Foresters ... 134
Sprague Meter Company, The ... Back Cover
Superior Meter Company, Inc. ... 2

Tapecoat Company, The ... 143

United Engineers & Constructors, Inc. ... 106

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Better check this—
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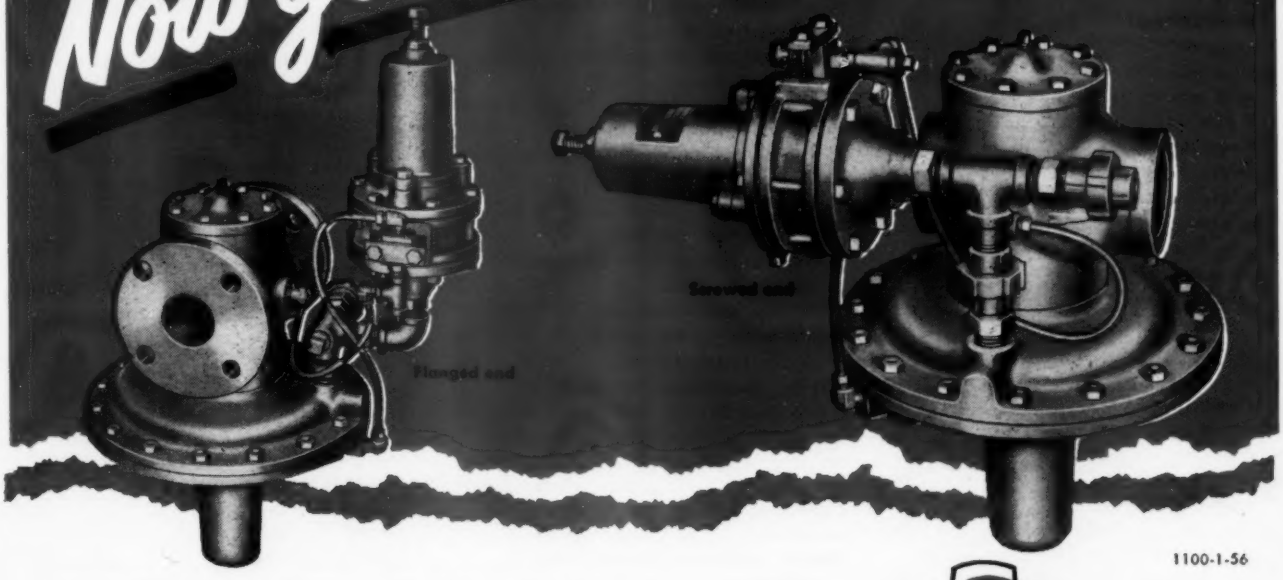

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2" flanged 250 lb.	rated for 400 psi
2" screwed end	rated for 400 psi
2" flanged 125 lb.	rated for 175 psi

All suitable for outlet pressure range from ounces to 150 psi with no change required in regulator or pilot—just change the pilot spring. It's accurate—versatile—compact! A good buy!

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And, if 400 psi is too low, why not try the all-steel Model '1200', good up to 1200 psi inlet and 600 psi outlet?

Full information on request.

ACCURATE CP MFG CO DEPENDABLE

Chaplin-Fulton
MANUFACTURING COMPANY
Pittsburgh 25, Pennsylvania

Index to Technical Data and Information

A

Air, composition 21
compression of 36
dry weight 21
saturated weight 21
Annuity table 126
Anodes, galvanic 61
API and Baumé, degrees, comparison with specific gravity 21
Appliances, maximum consumption table 69
Areas and circumferences of circles 24
Areas and volumes 23
ASA code, transmission, and distribution piping systems (ASA B31.1.8-1955)
construction classifications 44
definitions of terms and units 38
operating and maintenance, procedures 45
piping system components 42
scope and intent 38
scope diagram 39
Atmospheric pressure 22
Atmospheric volumetric multiplier chart for gases 29

B

Baking and cooking, commercial fuel requirements 117
Barometric readings, reduction of 22
Baumé and API, degrees, comparison with specific gravity 21
Bell pipe, cast iron 50-51
Bellamy demand-charge rate formula 123
Blowers, positive, and exhausters, power requirements of 35
Brake horsepower, engines 35
gas engines, Btu per hour 123
natural gas compressing 37
requirements per MMcf compressed 37

C

Carbonization, products of high and low temperature 96
Carbureting oils, characteristics 99
Cast iron pipe 50
Cathodic protection 61
Circles, circumferences and areas 24
Cities, U. S. and Canada, degree-days and minimum temperature for 118
Coal, heating value and analysis 97
Coal, selected, analysis of 96
Coal types, analyses, used in or suitable for by-product coke ovens 96
Coke ovens, by products, operating results 97
coal types used 96
Combustion, characteristics, typical gases 120
constants, gas 102
Commercial cooking, comparison of gas and electricity in 117
Compound interest table 127
Compressibility factors, determination of 26
table for, at reduced temperatures and pressures 27
Compressing air and gas 36
Conversions, atmospheric pressures 22
energy units 18
measures 17
mercury vacuum 22
pressure 18
specific gravity, NGAA 34
temperature 19
viscosity 20
weights 17
Cooking and baking, commercial, fuel requirements 117
Correction factors, oil temperature, ... 125
Corrosion, cathodic protection equipment 61
control methods 60
galvanic anodes 61
protective coatings 62
rectifier units 61

D

Degree days, U. S. and Canadian cities 118
Dehydration, absorption with liquids 91
chemical methods 91
combination methods 91
processes and drying, agents, comparison of 91
physical and physicochemical methods 91
with solids 91
Demand-charge rate formula, Bellamy 123
Design, gas service 55
Design of large volume gas measurement facilities 72
Deviation of gases from ideal gas laws 25
Dew point for various fuels 97
Distribution system, piping code, ASA 38
Drill sizes, standard twist 24
Drying agents and dehydration processes 91

E

Economy, average, of industrial furnaces 121
Electric motors, efficiencies 35
horsepower calculations 35
synchronous speeds 35
Electric vs. gas, comparisons, commercial cooking and baking requirements 117
relative costs 117
residential cooking 117
Energy units, conversion factors 18
Engines, gas, fuel consumption of 123
Engine horsepower 35
Error, percentage of, meters 71
Exhausters and positive blowers, power requirements of 35
Explosive limits of gas mixtures in air, calculating of selected industrial gases in air 113

F

Flow, approximate hourly, through orifice meter, methods of determining 75
Flue gas, dew points 97
Formulas, gas flow, Fritzsche, low pressure 53
Panhandle, high pressure 52
Pole, low pressure 53
Spitzglass, low pressure 53
Weymouth, high pressure 52
Fritzsche formula, low pressure gas flow 53
Fuel consumption, approximate, for water heating 116
of gas engines 123
of typical industrial furnaces 121
Furnaces, industrial, average economy of 121
typical, fuel consumption of 121
Fusion temperatures, representative, of refractories 122

G

Gas and air, compressing 123
Gas distribution piping systems 38
Gas engines, fuel consumption 123
Gas holders, wet seal, dimensions 95
Gas mixtures, explosive limits in air 113
Gas oil efficiency 99
Gas service design, ASA piping code 57
building entrances 58
construction specifications 57
main connections 57
meter installations 59
pipe capacity 116
pipe sizing 55
pressure ranges 55
regulators 59
service facilities 57
specific gravity multipliers 116
Gas transmission piping systems 38
Gas vs. electric, comparisons, commercial cooking and baking requirements 117
relative costs 117
residential cooking 117
Gases, analyses of typical 26
atmospheric volumetric multiplier chart 29
combustion characteristics 120
combustion constants 102
physical constants 103
compressibility factors 26
compressibility factors table 27
compression of 35
compression horsepower 36
compression temperatures 36
deviation from ideal gas laws 25
explosive limits, mixtures, in air 113
flow formulas, high pressure 52
flow formulas, low pressure 53
gal of water per MMcf 31

ignition temperatures, mixtures, in air ... 113
interchangeability of various ... 100
moisture content of compressed natural ... 32
properties of ... 25
vapor pressures, psia ... 30
water vapor in saturated ... 31

H

Heating gas, cost calculations ... 114
industrial, furnaces ... 119
requirements, estimating ... 115
Heating, industrial, operations ... 119
Heating value of coal, calculating from analysis ... 97
Holders, gas telescopic wet seal, dimension data on ... 95
Horsepower, boiler ... 35
brake ... 35
electrical ... 35
engine ... 35
indicated ... 35
requirements of blowers and exhausters ... 35
water ... 35
Hot water, approximate fuel consumption for ... 116

I

Ignition temperatures, gas, and explosive limits in air ... 113
Industrial furnaces, economy ... 121
fuel consumption ... 121
Industrial heating operations, material, operations, and temperature ranges ... 119
Interchangeability of various gases ... 100
Isobutane, see LP gases

K

Knoy's formula ... 101

L

Leakage, gas mains ... 134, 138
meters ... 134, 138
service lines ... 138
Liquefied petroleum gas, see LP gases
Losses, gas ... 129
LP gases, dew points, chart ... 107
properties of ... 109
vapor pressures ... 105
vaporization of liquid in tanks ... 111

M

Measurement, design of large volume facilities ... 72
factors for high pressure ... 70
high pressure with PD meters ... 70
orifice meters ... 75-90
Measures and weights, English ... 17
Metric ... 17
Meters, high pressure PD measurements ... 70
leak losses ... 133, 135
orifice, approximate hourly flow ... 75
orifice, factors ... 78-90
orifice, flow calculations ... 76
orifice, flow constant calculation ... 76
percentage of error ... 71
proof testing ... 71
sizing for domestic and small commercial loads ... 69

N

Natural gas, temporary-enthalpy diagram ... 68
NGAA volume correction factors ... 33

O

Odorants, properties of, for natural gas ... 94
Odorization, methods and equipment ... 92
Oil-Gas, efficiency of ... 99
interchangeability ... 101
Oils, carbureting, characteristics ... 99
petroleum, analyses and physical properties ... 98
petroleum, heating value ... 124-125
temperature correction factors ... 125
Orifice meters, duplex differential type ... 72
flow constant determination ... 76
flow factors, tables ... 78-90
large volume design ... 72
method of determining approximate hourly flow ... 75
simplex differential type ... 72

P

Panhandle formula, high pressure gas flow ... 52
Petroleum oils, analyses and physical properties ... 98
Physical constants of gas ... 103
Pipe
Steel, line
API Plain-End, regular weight ... 49
API Plain-End, standard weight ... 48
API Threaded, standard weight ... 48
Cast Iron
ASA thicknesses, mold cast ... 51
ASA thicknesses, pit cast ... 51
ASA weight, mechanical point ... 50
Pipe, capacity cu ft per hour ... 116
Pipe Coatings, asphalt ... 62
coal tar ... 62
plastic tapes ... 64
waxes and greases ... 63
wrappers ... 64
Pipe, protective coatings ... 62
Plastic tapes, pipe protection ... 64
Pole formula, low pressure gas flow ... 53
Pre-heated air, savings with gas ... 122
Present worth table ... 128
Pressure, atmospheric and altitude ... 22
atmospheric conversion ... 22
mercury vacuum, absolute ... 22
vapor, LPG ... 105
Pressure conversion table ... 18
Proof testing gas meters ... 71
Propane, see LP gases
Purging operations, safe end-points, involving combustible and inert gases ... 113

R

Rapid survey method of gas requirements and costs ... 114
Rectifiers, cathodic protection ... 61
Refractories, fusion temperatures ... 122
physical classifications ... 122
Regulators, determining capacity ... 65
determining pressure cuts ... 67
freezing problems ... 68

S

Safe end-points in purging operations involving gases ... 113
Service line sizes, guide for determining ... 53, 54, 55, 56
Space heating equipment, heat delivery ... 115
Specific gravity, conversion factors, NGAA ... 34
conversion multipliers ... 116
Spitzglass formula, low pressure gas flow ... 53
Steel Pipe ... 48
Steel sheets, gage, thickness and weight ... 24
Storage of gases, deviations from ideal gas laws ... 25
Substitute gas calculations, Knoy's formula for ... 101
Survey method, rapid, of gas requirements and costs ... 114
Tank formulas ... 104

T

Temperatures, conversion table ... 19
correction factors, oils ... 125
fusion, refractories ... 122
ranges, industrial heating operations ... 119
U. S. cities and Canadian ... 118
Testing gas meters ... 71
Twist drills, standard-sizes ... 24

U

Unaccounted-for gas ... 129

V

Vacuum mercury, absolute pressure ... 22
Vapor pressures, for gases in psia ... 30
LPG ... 105
of water ... 31
Viscosity conversion table ... 20
Volumes and areas ... 23
Volume correction factors, NGAA ... 33

W

Water, content of compressed natural gas ... 32
gal per MMcf of gas ... 31
vapor in saturated gas ... 31
vapor pressure ... 31
Water heaters, capacities ... 116
fuel consumption ... 116
Weights and measures, English ... 17
Metric ... 17
Weymouth formula, high pressure gas flow ... 52

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DUBUQUE, IOWA

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Diamond Line Quality Gas Service Stops

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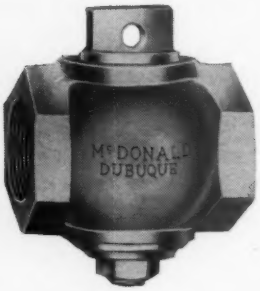

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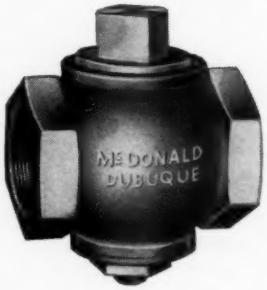

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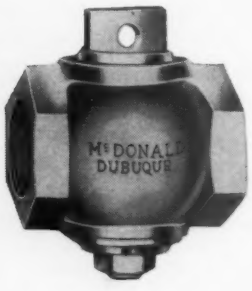

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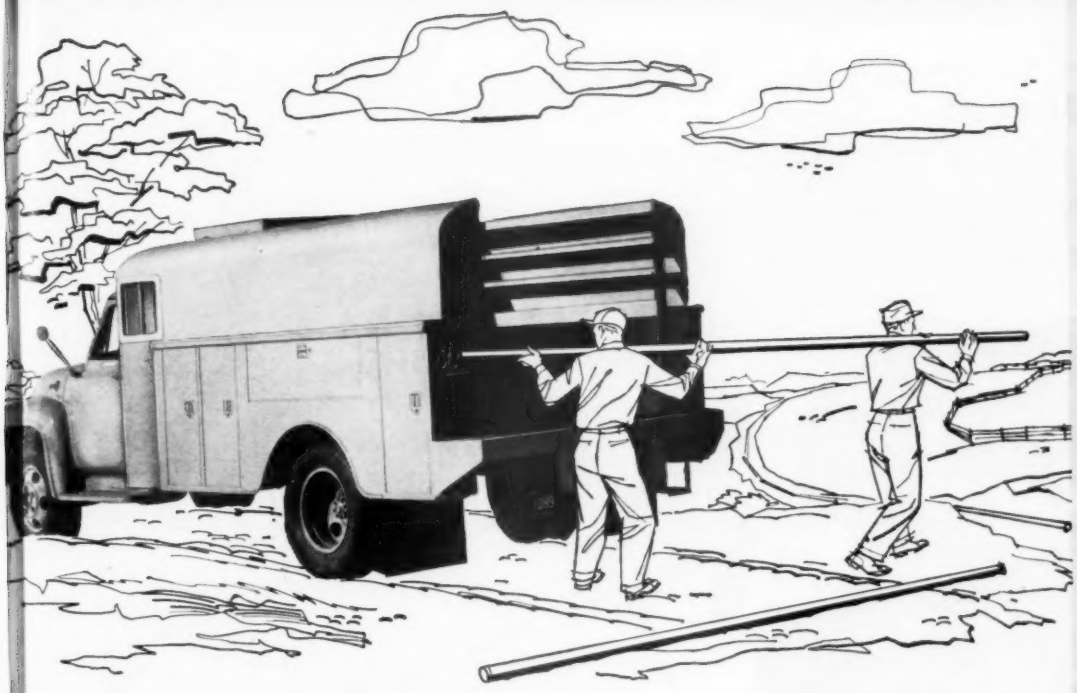

Crew unloading gas pipe from full-length tunnel in 7102C. Three vertical and one horizontal compartment with optional inserts are contained on the right side.

Comfortable 4-man crew compartment contains sliding windows with air scoops, spring seat and folding shelf. Bodies can be furnished with compartments made to order.

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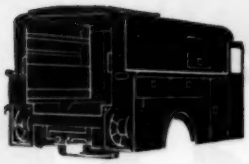
This is truly the opportunity gas companies have been waiting for—the chance to buy quality at limited-budget prices.

You can *now* buy Holan, the name that *means* work simplification, at a price that fits your purse.

Write for catalogs and price information on Holan 7000 and 7000C Bodies.

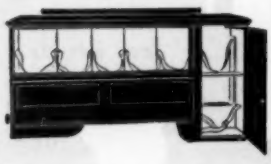


Air compressor bodies with hose reels in rear compartments.

Air compressor bodies with left handed compartments and air winch for backfilling.

Air compressor bodies with pipe compartment and provisions for oxygen and acetylene tanks.

Air compressor with skid-mounting and independent gasoline engine.



General service bodies with special gas meter compartments.

Service bodies for chassis up to 1½ tons. Lengths 72″, 75″, 84″, 90″ and 102″. Optional compartment arrangements.

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THE MODEL "O"

a pipe Beveler with a cutting Range of 1½" to 4"

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Employing the same split-gear horseshoe principle which has made its larger models so popular for years, H & M now offers the maximum in speed and *quality* of *bevels* for beveling small-diameter pipe! Built to withstand any job conditions, the H & M Model "O" can be operated easily and efficiently by unskilled operators — *with perfect bevels every time!* Change from one size of pipe to another can be made in a matter of seconds, with precision-made adapters, and a quick operating boomer strap allows rapid transfer from one pipe to another. *For detailed information on the fast-selling Model "O", contact your nearest H & M dealer immediately, or contact the factory at once!*

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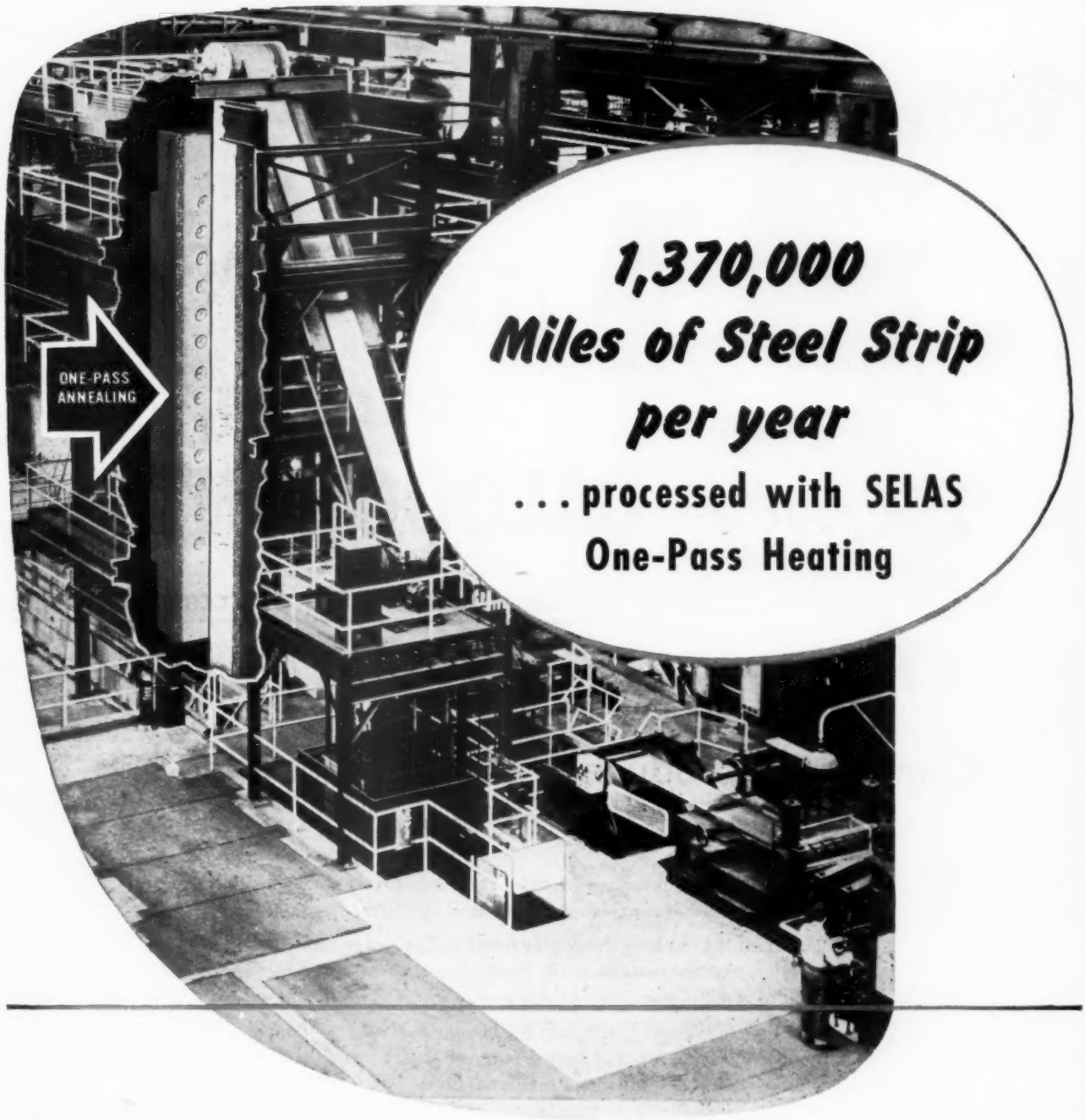

Enough steel strip to go around the world 55 times, is processed per year in Selas one-pass Gradiation furnace installations throughout the steel industry.

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a sulfide odorant at a mercaptan price!

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3882

Weights and Measures

English Units

Length

1000 mils	= 1 inch
12 inches	= 1 foot
3 feet	= 1 yard
5280 feet	= 1 mile
4 inches	= 1 hand
9 inches	= 1 span
2½ feet	= 1 pace
16½ feet or 5½ yards	= 1 rod
1 knot or nautical mile	= 6080.26 feet = ⅓ league
7.92 inches	= 1 link
25 links	= 1 rod
100 links or 66 feet or 4 rods	= 1 chain
10 chains	= 1 furlong
8 furlongs	= 1 mile

Surface

144 square inches	= 1 square foot
9 square feet	= 1 square yard
30¼ square yards	= 1 square rod
160 square rods	= 1 acre
640 acres	= 1 square mile
625 square links	= 1 square rod
16 square rods	= 1 square chain
10 square chains	= 1 acre
640 acres	= 1 square mile
36 square miles	= 1 township

Volume

1728 cubic inches	= 1 cubic foot
27 cubic feet	= 1 cubic yard
128 cubic feet	= 1 cord
24¾ cubic feet	= 1 perch

Troy Weight

24 grains (gr.)	= 1 pennyweight (dwt.)
20 pennyweights	= 1 ounce (oz.)
12 ounces	= 1 pound (lb.)

Avoirdupois Weight

16 drams (dr.)	= 1 ounce (oz.)
16 ounces	= 1 pound (lb.)
25 pounds	= 1 quarter (qr.)
4 quarters	= 1 hundred weight (cwt.)
20 hundred weight (2000 pounds)	= 1 ton (T.)

Apothecaries' Weight

20 grains (gr.)	= 1 scruple (sc.)
3 scruples	= 1 dram (dr.)
8 drams	= 1 ounce (oz.)
12 ounces	= 1 pound (lb)

Dry Measure

2 pints (pt.)	= 1 quart (qt.)
8 quarts	= 1 peck (pk.)
4 pecks	= 1 bushel (bu.)
36 bushels	= 1 chaldron (ch.)

Liquid Measure

4 gills (gi.)	= 1 pint (pt.)
2 pints	= 1 quart (qt.)
4 quarts	= 1 gallon (gal.)
31½ gallons	= 1 barrel (bar.)
63 gallons	= 1 hogshead (hhd.)

Apothecaries' Fluid Measure

60 minims	= 1 fluid-drachm
8 fluid-drachms	= 1 fluid-ounce
16 fluid-ounces	= 1 pint
8 pints	= 1 gallon

Circular Measure

60 seconds (″)	= 1 minute (′)
60 minutes	= 1 degree (°)
30 degrees	= 1 sign (s)
12 signs, or 360 degrees	= 1 circle (cir.)

Metric Units

Length

Centimeter	=	0.3937 inch.
Meter	=	3.28 feet.
Meter	=	1.094 yards.
Kilometer	=	0.621 statute mile.
Kilometer	=	0.5396 nautical mile.
Inch	=	2.540 centimeters.
Foot	=	0.305 meter.
Yard	=	0.914 meter.
Statute mile	=	1.61 kilometers.
Nautical mile	=	1.853 kilometers.

Area

Square centimeter	=	0.155 square inch.
Square meter	=	10.76 square feet.
Square meter	=	1.196 square yards.
Hectare	=	2.47 acres.
Square kilometer	=	0.386 square mile.
Square inch	=	6.45 square centimeters.
Square foot	=	0.0929 square meter.
Square yard	=	0.836 square meter.
Acre	=	0.405 hectare.
Square mile	=	2.59 square kilometers.

Volume

Cubic centimeter	=	0.0610 cubic inch.
Cubic meter	=	35.3 cubic feet.
Cubic meter	=	1.308 cubic yards.
Cubic inch	=	16.39 cubic centimeters.
Cubic foot	=	0.0283 cubic meter.
Cubic yard	=	0.765 cubic meter.

Capacity

Milliliter	=	0.0338 U. S. liquid ounce.
Milliliter	=	0.2705 U. S. apothecaries' dram.
Liter	=	1.057 U. S. liquid quarts.
Liter	=	0.2642 U. S. liquid gallon.
Liter	=	0.908 U. S. dry quart.
Dekaliter	=	1.135 U. S. pecks.
Hectoliter	=	2.838 U. S. bushels.
U. S. liquid ounce	=	29.57 milliliters.
U. S. apothecaries' dram	=	3.70 milliliters.
U. S. liquid quart	=	0.946 liter.
U. S. dry quart	=	1.101 liters.
U. S. liquid gallon	=	3.785 liters.
U. S. peck	=	0.881 dekaliter.
U. S. bushel	=	0.3524 hectoliter.

Weight

Gram	=	15.43 grains.
Gram	=	0.772 U. S. apothecaries' scruple.
Gram	=	0.2572 U. S. apothecaries' dram.
Gram	=	0.0353 avoirdupois ounce.
Gram	=	0.03215 troy ounce.
Kilogram	=	2.205 avoirdupois pounds.
Kilogram	=	2.679 troy pounds.
Metric ton	=	0.984 gross or long ton.
Metric ton	=	1.102 short or net tons.
Grain	=	0.0648 gram.
U. S. apothecaries' scruple	=	1.296 grams.
U. S. apothecaries' dram	=	3.89 grams.
Avoirdupois ounce	=	28.35 grams.
Troy ounce	=	31.10 grams.
Avoirdupois pound	=	0.4536 kilogram.
Troy pound	=	0.373 kilogram.
Gross or long ton	=	1.016 metric tons.
Short or net ton	=	0.907 metric ton.

PRESSURE CONVERSION TABLE

	Centimeters of water at 4°C	Inches of water at 4°C	Feet of water at 4°C	Centimeters of mercury	Inches of mercury	Grams per square centimeter	Ounces per square inch	Ounces per square foot	Pounds per square inch	Pounds per square foot	Dynes per square centimeter	Normal atmoshpere	45° Latitude atmosphere
Centimeters of water at 4°C	1.000000	0.3937000	0.03280833	0.07355393	0.02895818	0.9999730	0.2275682	32.76983	0.01422301	2.048114	980.6385	$0.0_2$9678148	$0.0_2$9678632
Inches of water at 4°C	2.540005	1.000000	0.08333333	0.1868273	0.07355393	2.539936	0.5780245	83.23552	0.03612653	5.202220	2490.827	0.002458255	0.002458377
Feet of water at 4°C	30.48006	12.00000	1.000000	2.241928	0.8826471	30.47924	6.936294	998.8263	0.4335183	62.42664	29889.92	0.02949906	0.02950053
Centimeters of mercury	13.59547	5.352535	0.4460446	1.000000	0.3937000	13.59510	3.093896	445.5211	0.1933685	27.84507	13332.24	0.01315789	0.01315855
Inches of mercury	34.53255	13.59547	1.132956	2.540005	1.000000	34.53162	7.858513	1131.626	0.4911570	70.72661	33863.95	0.03342112	0.03342279
Grams per square centimeter	1.000027	0.3937106	0.03280922	0.07355591	0.02895896	1.000000	0.2275744	32.77071	0.01422340	2.048169	980.6650	$0.0_2$9678410	0.0.9678893
Ounces per square inch	4.394286	1.730031	0.1441692	0.3232170	0.1272505	4.394168	1.000000	144.0000	0.06250000	9.000000	4309.207	0.004252856	0.004253068
Ounces per square foot	0.03051588	0.01201410	0.001001175	0.002244563	$0.0_2$8836843	0.03051505	0.006944444	1.000000	$0.0_2$4340278	0.06250000	29.92505	$0.0_4$2953372	$0.0_2$2953520
Pounds per square inch	70.30858	27.68049	2.306707	5.171473	2.036009	70.30669	16.00000	2304.000	1.000000	144.0000	68947.31	0.06804569	0.06804909
Pounds per square foot	0.4882541	0.1922256	0.01601880	0.03591300	0.01413895	0.4882409	0.1111111	16.00000	0.006944444	1.000000	478.8007	$0.0_3$4725395	$0.0_3$4725631
Dynes per square centimeter	0.001019744	$0.0_3$4014731	$0.0_4$3345609	$0.0_4$7500616	$0.0_4$2952992	0.001019716	$0.0_2$2320613	0.03341682	$0.0_4$1450383	0.002088552	1.000000	$0.0_6$9869231	$0.0_6$9869724
Normal atmosphere	1033.255	406.7927	33.89939	76.00000	29.92120	1033.228	235.1361	33859.60	14.69601	2116.225	1013250.	1.000000	1.000050
45° latitude atmosphere	1033.204	406.7724	33.89770	75.99620	29.91970	1033.176	235.1244	33857.91	14.69527	2116.119	1013200.	0.9999500	1.000000

Expressions like 0.0_3 and 0.0_6 stand for 0.000 and 0.000000.
This table is based on the following values and definitions from I.C.T.:
Standard acceleration of gravity, 980.665 cm per second per second. 1 l = 1000.027 cc, 1 cm = 0.3937 in.
[1]Adapted from *K. C. Testing Lab. Bull.* 25.
Adapted from "International Critical Table," McGraw-Hill Book Co.
By permission from "Gas Engineers' Handbook." Copyright 1934, McGraw-Hill Book Company, Inc.

45° latitude acceleration of gravity, 980.616 cm per second per second, 1 lb = 453.5924277 g. 1 normal atmosphere = pressure exerted on 1 sq cm by a vertical column of liquid 76 cm in height, of density 13.5951 g per cubic centimeter, at a place where the acceleration of gravity is standard.
45° latitude atmosphere differs from the normal atmosphere only in the value of gravity.

CONVERSION FACTORS FOR ENERGY UNITS

Acceleration of gravity = 980.665 cm per second per second

Units	Btu	Pcu[2]	Calories (large)	Foot-pounds	Foot-tons	Kilogram-meters	Horsepower-hours	Kilowatt-hours	Joules, inter-national	Pounds carbon[2]	Pounds water[2]
Btu	1.00000	0.555556	0.251983	777.979	0.388990	107.560	$0.0_3$392922	$0.0_3$293000	1,054.46	$0.0_4$687569	0.00103050
Pcu[2]	1.80000	1.00000	0.453569	1,400.36	0.700181	193.607	$0.0_3$707260	$0.0_3$527400	1,898.03	$0.0_3$123762	0.00185490
Calories (large)	3.96852	2.20474	1.00000	3,087.43	1.54372	426.853	0.00155932	0.00116278	4,184.66	$0.0_3$272863	0.00408958
Foot-pounds	0.00128538	$0.0_3$714101	$0.0_3$323894	1.00000	$0.0_3$500000	0.138255	$0.0_6$505051	$0.0_6$376617	1.35539	$0.0_6$883788	$0.0_3$132459
Foot-tons	2.57076	1.42820	0.647788	2,000.00	1.00000	276.510	0.00101010	$0.0_3$753233	2,710.77	$0.0_3$176758	0.00264918
Kilogram-meters	0.00929716	0.00516509	0.00234272	7.23300	0.00361650	1.00000	$0.0_3$365306	$0.0_3$272407	9.80351	$0.0_4$639244	$0.0_3$958076
Horsepower-hours	2,545.03	0.141391	641.304	1,979,980	989.999	273,743	1.00000	0.745694	2,683,640	0.174988	2.62266
Kilowatt-hours	3,412.97	1,896.09	860.009	2,655,220	1,327.61	367,098	1.34103	1.00000	3,598,850	0.234665	3.51707
Joules (international)	$0.0_3$948350	$0.0_3$526861	$0.0_3$238968	0.737797	$0.0_3$368898	0.102004	$0.0_4$372628	$0.0_4$277867	1.00000	$0.0_6$652056	$0.0_6$977278
Pounds carbon[2]	14,544	808.000	3,664.84	11,314,900	5,657.47	1,564,350	5.71466	4.26139	15,336,100	1.00000	14.9876
Pounds water[2]	970.40	539.111	244.524	754,951	377.476	104,376	0.381292	0.284327	1,023,250	0.0667217	1.00000

This table is based upon the following I.C.T. values:

1 Btu (mean)	= 1054.8	absolute joules
1 g-cal (mean)	= 4.186	absolute joules
1 ft-lb	= 1.35582	absolute joules
1 kg-m	= 9.80665	absolute joules
1 hp-hr	= $2.6845 \times 10_6$	absolute joules
1 kwhr	= $3.6000 \times 10_6$	absolute joules
1 international joule	= 1.00032	absolute joules

[1]Adapted from Van Nostrand's "Chemical Annual" and I.C.T.:
[2]Pcu refers to pound-Centigrade unit. The ton used is 2000 lb. "Pounds carbon" refers to pounds of carbon oxidized to CO_2 of 100 per cent efficiency equivalent to the corresponding number of heat units. "Pounds water" refers to pounds of water evaporated at 212° F at 100 per cent efficiency.
0.0_3 signifies 0.000.
1 cal (small) per gram = 1.8 Btu per pound.
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Temperature Conversion Table

°C	0	10	20	30	40	50	60	70	80	90
	F	F	F	F	F	F	F	F	F	F
—200	—328	—364	—364	—382	—400	—418	—436	—454	....	....
—100	—148	—166	—184	—202	—220	—238	—256	—274	—292	—310
—0	+32	+14	—4	—22	—40	—58	—76	—94	—112	—130
0	32	50	68	86	104	122	140	158	176	194
100	212	230	248	266	284	302	320	338	356	374
200	392	410	428	446	464	482	500	518	536	554
300	572	590	608	626	644	662	680	698	716	734
400	752	770	788	806	824	842	860	878	896	914
500	932	950	968	986	1004	1022	1040	1058	1076	1094
600	1112	1130	1148	1166	1184	1202	1220	1238	1256	1274
700	1292	1310	1328	1346	1364	1382	1400	1418	1436	1454
800	1472	1490	1508	1526	1544	1562	1580	1598	1616	1634
900	1652	1670	1688	1706	1724	1742	1760	1778	1796	1814
1000	1832	1850	1868	1886	1904	1922	1940	1958	1976	1994
1100	2012	2030	2048	2066	2084	2102	2120	2138	2156	2174
1200	2192	2210	2228	2246	2264	2282	2300	2318	2336	2354
1300	2372	2390	2408	2426	2444	2462	2480	2498	2516	2534
1400	2552	2570	2588	2606	2624	2642	2660	2678	2696	2714
1500	2732	2750	2768	2786	2804	2822	2840	2858	2876	2894
1600	2912	2930	2948	2966	2984	3002	3020	3038	3056	3074
1700	3092	3110	3128	3146	3164	3182	3200	3218	3236	3254
1800	3272	3290	3308	3326	3344	3362	3380	3398	3416	3434
1900	3452	3470	3488	3506	3524	3542	3560	3578	3596	3614
2000	3632	3650	3668	3686	3704	3722	3740	3758	3776	3794
2100	3812	3830	3848	3866	3884	3902	3920	3938	3956	3974
2200	3992	4010	4028	4046	4064	4082	4100	4118	4136	4154
2300	4172	4190	4208	4226	4244	4262	4280	4298	4316	4334
2400	4352	4370	4388	4406	4424	4442	4460	4478	4496	4514
2500	4532	4550	4568	4586	4604	4622	4640	4658	4676	4694
2600	4712	4730	4748	4766	4784	4802	4820	4838	4856	4874
2700	4892	4910	4928	4946	4964	4982	5000	5018	5036	5054
2800	5072	5090	5108	5126	5144	5162	5180	5198	5216	5234
2900	5252	5270	5288	5306	5324	5342	5360	5378	5396	5414
3000	5432	5450	5468	5486	5504	5522	5540	5558	5576	5594
3100	5612	5630	5648	5666	5684	5702	5720	5738	5756	5774
3200	5792	5810	5828	5846	5864	5882	5900	5918	5936	5954
3300	5972	5990	6008	6026	6044	6062	6080	6098	6116	6134
3400	6152	6170	6188	6206	6224	6242	6260	6278	6296	6314
3500	6332	6350	6368	6386	6404	6422	6440	6458	6476	6494
3600	6512	6530	6548	6566	6584	6602	6620	6638	6656	6674
3700	6692	6710	6728	6746	6764	6782	6800	6818	6836	6854
3800	6872	6890	6908	6926	6944	6962	6980	6998	7016	7034
3900	7052	7070	7088	7106	7124	7142	7160	7178	7196	7214
°C	0	10	20	30	40	50	60	70	80	90

°C	°F
1	1.8
2	3.6
3	5.4
4	7.2
5	9.0
6	10.8
7	12.6
8	14.4
9	16.2
10	18.0

°F	°C
1	1.56
2	1.11
3	1.67
4	2.22
5	2.78
6	3.33
7	3.89
8	4.44
9	5.00
10	5.56
11	6.11
12	6.67
13	7.22
14	7.78
15	8.33
16	8.89
17	9.44
18	10.00

Examples: 1347° C = 2444° F +12.6° F = 2456.6° F. 3367° F = 1850° C + 2.78° C = 1852.78° C.

Bureau of Standards—M126

VISCOSITY CONVERSION TABLE

The following table will give a comparison of various viscosity ratings so that if the viscosity is given in terms other than Saybolt Universal, it can be translated quickly by following horizontally to the Saybolt Universal column.

Kinematic Viscosity Centipoises = K	Seconds Saybolt Universal	Seconds Saybolt Furol	Seconds Redwood	Seconds Redwood Admiralty	Degrees Engler	Degrees Barley
1.00	31	.....	29	.....	1.00	6200
2.56	35	.....	32.1	.....	1.16	2420
4.30	40	.....	36.2	5.10	1.31	1440
5.90	45	.....	40.3	5.52	1.46	1050
7.40	50	.....	44.3	5.83	1.58	838
8.83	55	.....	48.5	6.35	1.73	702
10.20	60	.....	52.3	6.77	1.88	618
11.53	65	.....	56.7	7.17	2.03	538
12.83	70	12.95	60.9	7.60	2.17	483
14.10	75	13.33	65.0	8.00	2.31	440
15.35	80	13.70	69.2	8.44	2.45	404
16.58	85	14.10	73.3	8.86	2.59	374
17.80	90	14.44	77.6	9.30	2.73	348
19.00	95	14.85	81.5	9.70	2.88	326
20.20	100	15.24	85.6	10.12	3.02	307
31.80	150	19.3	128	14.48	4.48	195
43.10	200	23.5	170	18.90	5.92	144
54.30	250	28.0	212	23.45	7.35	114
65.40	300	32.5	254	28.0	8.79	95
76.50	350	35.1	296	32.5	10.25	81
87.60	400	41.9	338	37.1	11.70	70.8
98.60	450	46.8	381	41.7	13.15	62.9
110.	500	51.6	423	46.2	14.60	56.4
121.	550	56.6	465	50.8	16.05	51.3
132.	600	61.4	508	55.4	17.50	47.0
143	650	66.2	550	60.1	19.00	43.4
154	700	71.1	592	64.6	20.45	40.3
165	750	76.0	635	69.2	21.90	37.6
176	800	81.0	677	73.8	23.35	35.2
187	850	86.0	719	78.4	24.80	33.2
198	900	91.0	762	83.0	26.30	31.3
209	950	95.8	804	87.6	27.70	29.7
220	1000	100.7	846	92.2	29.20	28.2
330	1500	150	1270	138.2	43.80	18.7
440	2000	200	1690	184.2	58.40	14.1
550	2500	250	2120	230	73.00	11.3
660	3000	300	2540	276	87.60	9.4
770	3500	350	2960	322	100.20	8.05
880	4000	400	3380	368	117.00	7.05
990	4500	450	3810	414	131.50	6.26
1100	5000	500	4230	461	146.00	5.64
1210	5500	550	4650	507	160.50	5.13
1320	6000	600	5080	553	175.00	4.70
1430	6500	650	5500	559	190.00	4.34
1540	7000	700	5920	645	204.50	4.03
1650	7500	750	6350	691	219.00	3.76
1760	8000	800	6770	737	233.50	3.52
1870	8500	850	7190	783	248.00	3.32
1980	9000	900	7620	829	263.00	3.13
2090	9500	950	8040	875	277.00	2.97
2200	10000	1000	8460	921	292.00	2.82

The viscosity is often expressed in terms of viscosimeters other than the Saybolt Universal. The formulas for the various viscosimeters are as follows:

Redwood	$K = .26\,t - \frac{188}{t}$	(British)	Saybolt Universal	$K = .22\,t - \frac{180}{t}$	American
Redwood Admiralty	$K = 2.396 - \frac{40.3}{t}$	(British)	Saybolt Furol	$K = 2.2\,t - \frac{203}{t}$	American
			Engler	$K = .147\,t - \frac{374}{t}$	German

$= \text{Engler Degrees} \times 51.3$

The Barbey measures the quantity of flow per hour under constant head instead of the time for a definite quantity under varying head as do the others.

The Saybolt Furol and Redwood Admiralty are especially designed for measuring the more viscous oils and give a reading in seconds approximately one-tenth of that given for the same oil by the Saybolt Universal and Redwood respectively.

If viscosity is given at any two temperatures, the viscosity at any other temperature can be obtained by plotting the viscosity against temperature in degrees Fahrenheit on special cross section paper. The points for a given oil lie in a straight line.

Courtesy Worthington Pump & Machinery Corp.

COMPARISON OF DEGREES BAUME AND API WITH SPECIFIC GRAVITY

The general relationship between degrees Baume′ and specific gravity is found in the following:

For liquids heavier than water—

$$\text{Sp. Gr.} = \frac{145}{145 - {}^\circ \text{ Baume}'} \text{ at } 60^\circ \text{ F.}$$

For liquids lighter than water—

$$\text{Sp. Gr.} = \frac{140}{130 + {}^\circ \text{ Baume}'} \text{ at } 60^\circ \text{ F.}$$

The corresponding relationship for degrees API is as follows.

$$\text{Sp. Gr.} = \frac{141.5}{131.5 + {}^\circ \text{ API}}$$

Deg.	Specific Gravity: Baumé: Liquids Heavier than Water	Specific Gravity: Baumé: Liquids Lighter than Water	Specific Gravity: API
0	1.000		
1.0	1.007		
2.0	1.014		
3.0	1.021		
4.0	1.028		
5.0	1.036		
6.0	1.043		
7.0	1.051		
8.0	1.058		
9.0	1.066		
10.0	1.074	1.000	1.000
11.0	1.082	.993	.993
12.0	1.090	.986	.986
13.0	1.098	.979	.979
14.0	1.107	.972	.973
15.0	1.115	.965	.966
16.0	1.124	.959	.959
17.0	1.133	.952	.953
18.0	1.142	.946	.947
19.0	1.151	.940	.940
20.0	1.160	.933	.934
21.0	1.169	.927	.928
22.0	1.179	.921	.922
23.0	1.188	.915	.916
24.0	1.198	.909	.910
25.0	1.208	.903	.904
26.0	1.218	.897	.898
27.0	1.229	.892	.893
28.0	1.239	.886	.887
29.0	1.250	.880	.882
30.0	1.261	.875	.876
31.0	1.272	.870	.871
32.0	1.283	.864	.865
33.0	1.295	.859	.860
34.0	1.306	.854	.855
35.0	1.318	.848	.850
36.0	1.330	.843	.845
37.0	1.343	.838	.840
38.0	1.355	.833	.835
39.0	1.368	.828	.830
40.0	1.381	.823	.825
41.0	1.394	.819	.820
42.0	1.408	.814	.816
43.0	1.422	.809	.811
44.0	1.436	.805	.806
45.0	1.450	.800	.802
46.0	1.465	.795	.797
47.0	1.480	.791	.793
48.0	1.495	.786	.788
49.0	1.510	.782	.784
50.0	1.526	.778	.780
51.0	1.543	.773	.775
52.0	1.559	.769	.771
53.0	1.576	.765	.767
54.0	1.593	.761	.763
55.0	1.611	.757	.759
56.0	1.629	.753	.755
57.0	1.648	.749	.751
58.0	1.667	.745	.747
59.0	1.686	.741	.743
60.0	1.706	.737	.739
61.0	1.726	.733	.735
62.0	1.747	.729	.731
63.0	1.768	.725	.728
64.0	1.790	.722	.724
65.0	1.812	.718	.720
66.0	1.835	.714	.717
67.0	1.859	.711	.713
68.0	1.883	.707	.709
69.0	1.908	.703	.706
70.0	1.933	.700	.702
71.0	1.959	.696	.699
72.0	1.986	.693	.695
73.0		.690	.692
74.0		.686	.689
75.0		.683	.685
76.0		.680	.682
77.0		.676	.679
78.0		.673	.675
79.0		.670	.672
80.0		.667	.669

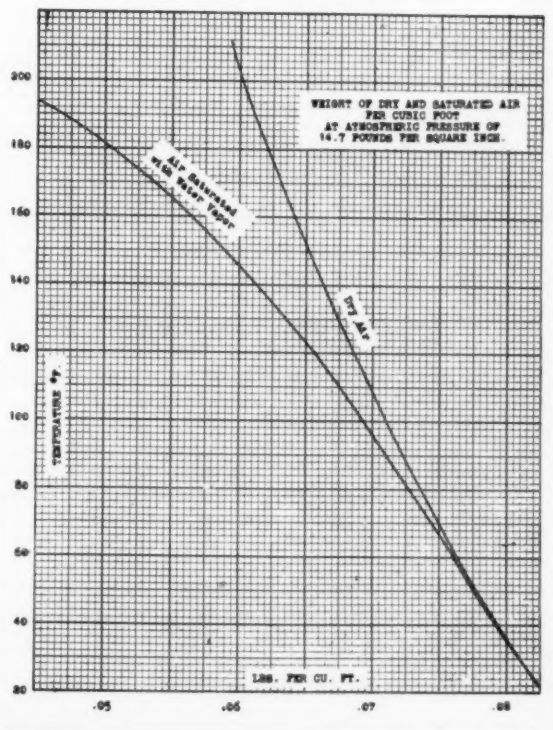
COMPOSITION OF AIR

	Dry Air[1]	Per cent by Volume Atmospheric Air at Sea Level (Average[2])
Nitrogen	78.03	77.08
Oxygen	20.99	20.75
Argon	.94	.93
Carbon Dioxide	.03	.03
Hydrogen	.01	.01
Water Vapor	—	1.20
Krypton, Neon, Niton, Xenon	Trace	Trace
	100.00	100.00

[1]International Critical Tables.

[2]Guide American Society of Heating and Ventilating Engineers.

WEIGHT OF DRY AND SATURATED AIR AT DIFFERENT TEMPERATURES IN LBS. PER CU. FT.



REDUCTION OF BAROMETRIC READINGS

This table gives the corrections in inches of mercury to convert readings at various temperatures to readings at standard temperature.

	Observed reading of barometer in inches						
°F	24	25	26	27	28	29	30
0	+0.063	+0.065	+0.068	+0.070	+0.073	+0.075	+0.078
2	+0.058	+0.061	+0.063	+0.065	+0.068	+0.070	+0.073
4	+0.054	+0.056	+0.058	+0.061	+0.063	+0.065	+0.067
6	+0.049	+0.052	+0.054	+0.056	+0.058	+0.060	+0.062
8	+0.045	+0.047	+0.049	+0.051	+0.053	+0.054	+0.056
10	+0.011	+0.042	+0.044	+0.046	+0.047	+0.049	+0.051
12	+0.036	+0.038	+0.039	+0.041	+0.042	+0.042	+0.045
14	+0.032	+0.033	+0.035	+0.036	+0.037	+0.039	+0.040
16	+0.028	+0.029	+0.030	+0.031	+0.032	+0.033	+0.034
18	+0.023	+0.024	+0.025	+0.026	+0.027	+0.028	+0.029
20	+0.019	+0.020	+0.020	+0.021	+0.022	+0.023	+0.024
22	+0.014	+0.015	+0.016	+0.016	+0.017	+0.017	+0.018
24	+0.010	+0.011	+0.011	+0.011	+0.012	+0.012	+0.013
26	+0.006	+0.006	+0.006	+0.006	+0.007	+0.007	+0.007
28	+0.001	+0.001	+0.001	+0.002	+0.002	+0.002	+0.002
30	−0.003	−0.003	−0.003	−0.003	−0.003	−0.004	−0.004
32	−0.007	−0.008	−0.008	−0.008	−0.009	−0.009	−0.009
34	−0.012	−0.012	−0.013	−0.013	−0.014	−0.014	−0.015
36	−0.016	−0.017	−0.017	−0.018	−0.019	−0.019	−0.020
38	−0.020	−0.021	−0.022	−0.023	−0.024	−0.025	−0.026
40	−0.025	−0.026	−0.027	−0.028	−0.029	−0.030	−0.031
42	−0.029	−0.030	−0.032	−0.033	−0.034	−0.035	−0.036
44	−0.033	−0.035	−0.036	−0.038	−0.039	−0.040	−0.042
46	−0.038	−0.039	−0.041	−0.043	−0.044	−0.046	−0.047
48	−0.042	−0.044	−0.046	−0.047	−0.049	−0.051	−0.053
50	−0.046	−0.048	−0.050	−0.052	−0.054	−0.056	−0.058
52	−0.051	−0.053	−0.055	−0.057	−0.059	−0.061	−0.064
54	−0.055	−0.057	−0.060	−0.062	−0.064	−0.067	−0.069
56	−0.060	−0.062	−0.064	−0.067	−0.069	−0.072	−0.074
58	−0.064	−0.066	−0.069	−0.072	−0.074	−0.077	−0.080
60	−0.068	−0.071	−0.074	−0.077	−0.080	−0.082	−0.085
62	−0.073	−0.076	−0.079	−0.082	−0.085	−0.088	−0.091
64	−0.077	−0.080	−0.083	−0.086	−0.090	−0.093	−0.096
66	−0.081	−0.085	−0.088	−0.091	−0.095	−0.098	−0.101
68	−0.085	−0.089	−0.093	−0.096	−0.100	−0.103	−0.107
70	−0.090	−0.094	−0.097	−0.101	−0.105	−0.109	−0.112
72	−0.094	−0.098	−0.102	−0.106	−0.110	−0.114	−0.118
74	−0.098	−0.103	−0.107	−0.111	−0.115	−0.119	−0.123
76	−0.103	−0.107	−0.111	−0.116	−0.120	−0.124	−0.128
78	−0.107	−0.112	−0.116	−0.120	−0.125	−0.129	−0.341
80	−0.111	−0.116	−0.121	−0.125	−0.130	−0.135	−0.139
82	−0.116	−0.121	−0.125	−0.130	−0.135	−0.140	−0.145
84	−0.120	−0.125	−0.130	−0.135	−0.140	−0.145	−0.150
86	−0.124	−0.130	−0.135	−0.140	−0.145	−0.150	−0.155
88	−0.129	−0.134	−0.139	−0.145	−0.150	−0.155	−0.161
90	−0.133	−0.138	−0.144	−0.150	−0.155	−0.161	−0.166
92	−0.137	−0.143	−0.149	−0.154	−0.160	−0.166	−0.172
94	−0.142	−0.147	−0.153	−0.159	−0.165	−0.171	−0.177
96	−0.146	−0.152	−0.158	−0.164	−0.170	−0.176	−0.182
98	−0.150	−0.156	−0.163	−0.169	−0.175	−0.181	−0.188
100	−0.154	−0.161	−0.167	−0.174	−0.180	−0.187	−0.193

From Table 44 of Smithsonian Meteorological Tables, 1939.
Example:

Observed height of barometer	= 29.502
Attached thermometer, 68 degrees F. Reduction for temperature	= 0.105
Barometer reading corrected for temperature	= 29.397

ATMOSPHERIC PRESSURE

This table is compiled from elevations and normal atmospheric pressures at United States Weather Bureau stations.

Elevation in feet	Inches mercury	Pounds absolute	Elevation in feet	Inches mercury	Pounds absolute
0	30.00	14.73	2000	27.90	13.70
100	29.89	14.68	2500	27.39	13.45
200	29.78	14.63	3000	26.90	13.21
300	29.67	14.57	3500	26.41	12.97
400	29.56	14.52	4000	25.93	12.74
500	29.45	14.46	4500	25.46	12.50
600	29.34	14.41	5000	25.00	12.28
800	29.13	14.31	5500	24.54	12.05
1000	28.93	14.21	6000	24.10	11.84
1500	28.41	13.95	6500	23.67	11.63

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ALTITUDE AND ATMOSPHERIC PRESSURE

This table from the United States Weather Bureau gives altitudes and average atmospheric pressures.

Location	Elevation in feet above sea level	Average atmospheric pressure pounds	Location	Elevation in feet above sea level	Average atmospheric pressure pounds
Abilene, Tex.	1738	13.85	Hartford, Conn.	159	14.66
Albany, N. Y.	97	14.70	Helena, Mont.	4110	12.67
Amarillo, Tex.	3676	12.90	Houston, Tex.	138	14.68
Asheville, N. C.	2253	13.62	Indianapolis, Ind.	822	41.32
Atlanta, Ga.	1173	14.16	Kansas City, Mo.	963	14.23
Atlantic City, N. J.	52	14.72	Keokuk, Iowa	614	14.42
Austin, Tex.	605	14.43	Knoxville, Tenn.	995	14.25
Baker, Ore.	3471	13.01	Lander, Wyo.	5372	12.10
Baltimore, Md.	123	14.69	Lincoln, Neb.	1189	14.11
Binghamton, N. Y.	871	14.29	Los Angeles, Cal.	338	14.55
Birmingham, Ala.	700	14.39	Louisville, Ky.	525	14.48
Bismarck, N. Dak.	1674	13.84	Madison, Wis.	974	14.23
Boise, Idaho	2739	13.35	Memphis, Tenn.	399	14.55
Boston, Mass.	125	14.67	Miami, Fla.	25	14.74
Brownsville, Tex.	57	14.69	Milwaukee, Wis.	681	14.38
Buffalo, N. Y.	767	14.33	Minneapolis, Minn.	918	14.23
Burlington, Vt.	403	15.51	Montgomery, Ala.	223	14.65
Cairo, Ill.	358	14.57	Nashville, Tenn.	546	14.48
Charleston, S. C.	48	14.74	New Orleans, La.	53	14.73
Charlotte, N. C.	779	14.36	New York, N. Y.	314	14.58
Chattanooga, Tenn.	762	14.37	North Platte, Neb.	2821	13.29
Cheyenne, Wyo.	6088	11.79	Oklahoma City, Okla.	1214	14.11
Chicago, Ill.	673	14.39	Omaha, Neb.	1105	14.16
Cincinnati, Ohio	627	14.43	Parkesburg, W. Va.	637	14.45
Cleveland, Ohio	762	14.34	Philadelphia, Pa.	114	14.70
Columbia, N. C.	784	14.34	Pittsburgh, Pa.	842	14.31
Columbus, Ohio	822	14.33	Pocatello, Idaho	4477	12.52
Concord, N. H.	289	14.57	Pueblo, Colo.	4685	12.42
Corpus Christi, Tex.	20	14.72	Rapid City, S. Dak.	3259	13.06
Dallas, Tex.	512	14.47	Reno, Neb.	4532	12.51
Dayton, Ohio	899	14.29	Rochester, N. Y.	523	14.46
Del Rio, Tex.	944	14.22	Roswell, N. Mex.	3566	12.95
Denver, Colo.	5292	12.14	Sacramento, Cal.	69	14.69
Des Moines, Iowa	861	14.29	St. Louis, Mo.	568	14.45
Detroit, Mich.	730	14.36	St. Paul, Minn.	837	14.28
Dodge City, Kan.	2509	13.46	Salt Lake City, Utah	4360	12.50
Dubuque, Iowa	700	14.37	San Antonio, Tex.	693	14.38
Duluth, Minn.	1133	14.12	San Diego, Cal.	87	14.68
Elkins, W. Va.	1947	13.77	San Francisco, Cal.	155	14.66
El Paso, Tex.	3778	12.86	Santa Fe, N. Mex.	7013	11.44
Erie, Pa.	714	14.37	Seattle, Wash.	125	14.69
Evansville, Ind.	431	14.53	Shreveport, La.	249	14.62
Fort Smith, Ark.	457	14.50	Spokane, Wash.	1929	13.74
Fort Wayne, Ind.	856	14.29	Syracuse, N. Y.	597	14.43
Fort Worth, Tex.	670	14.39	Toledo, Ohio	628	14.42
Grand Rapids, Mich.	707	14.37	Washington, D. C.	112	14.70
Harrisburg, Pa.	374	14.55	Yuma, Ariz.	141	14.61

MERCURY VACUUM — ABSOLUTE PRESSURE

Based on atmospheric pressure of 14.4 pounds and mercury at 32 degrees F.

Inches mercury vacuum	Inches mercury absolute	Pounds per square inch absolute	Inches mercury vacuum	Inches mercury absolute	Pounds per square inch absolute
1	28.32	13.91	16	13.32	6.54
2	27.32	13.42	17	12.32	6.05
3	26.32	12.93	18	11.32	5.56
4	25.32	12.44	19	10.32	5.07
5	24.32	11.94	20	9.32	4.58
6	23.32	11.45	21	8.32	4.09
	22.32	10.96	22	7.32	3.59
	21.32	10.47	23	6.32	3.10
9	0.32	9.98	24	5.32	2.61
10	19.32	9.49	25	4.32	2.12
11	18.32	9.00	26	3.32	1.63
12	17.32	8.51	27	2.32	1.14
13	16.32	8.01	28	1.32	0.65
14	15.32	7.52	29	0.32	0.16
15	14.32	7.03	30	....	....

AREAS AND VOLUMES

Square

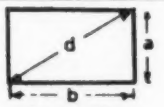
A = area.

$A = s^2$

$A = \frac{1}{2} d^2$

$s = 0.7071\ d = \sqrt{A}$

$d = 1.414\ s = 1.414\ \sqrt{A}$



Rectangle

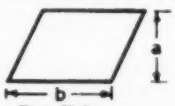
A = area.

$A = ab$

$d = \sqrt{a^2 + b^2}$

$a = A \div b$

$b = A \div a$



Parallelogram

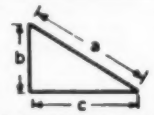
A = area.

$A = ab$

$a = A \div b$

$b = A \div a$

Note that dimension a is measured at right angles to line b.



Right-angled triangle

A = area.

$A = \frac{bc}{2}$

$A = \sqrt{b^2 + c^2}$

$b = \sqrt{a^2 - c^2}$

$c = \sqrt{a^2 - b^2}$

Acute-angled triangle

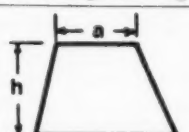
A = area.

$$A = \frac{bh}{2} = \frac{b}{2}\sqrt{a^2 - \left(\frac{a^2 + b^2 - c^2}{2b}\right)^2}$$

Obtuse-angled triangle

A = area.

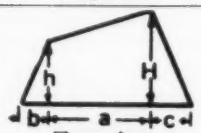
$$A = \frac{bh}{2} = \frac{b}{2}\sqrt{a^2 - \left(\frac{c^2 - a^2 - b^2}{2b}\right)^2}$$



Trapezoid

A = area.

$$A = \frac{(a + b)\,h}{2}$$



Trapezium

A = area.

$$A = \frac{(H + h)\,a + bh + cH}{2}$$

Regular polygon

A = area; n = number of sides.

$x = 360° \div n$ $B = 180° - x$

$$A = \frac{nsr}{2} = \frac{ns}{2}\sqrt{R^2 - \frac{s^2}{4}}$$

$$R = \sqrt{r^2 + \frac{s^2}{4}} \qquad r = \sqrt{R^2 - \frac{s^2}{4}}$$

$s = 2\sqrt{R^2 - r^2}$

Circle

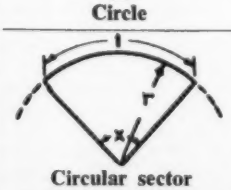
A = area; C = circumference.

$A = 0.7854\ d^2$

$C = 3.1416\ d$

$r = C \div 6.2832 = 0.564\ \sqrt{A}$

$d = C \div 3.1416 = 1.128\ \sqrt{A}$



Circular sector

A = area; l = length of arc; x = angle, in degrees.

$l = \frac{2A}{r}$

$A = \frac{1}{2} rl$

$x = \frac{57.296\,l}{r}$ $\qquad r = \frac{2A}{l}$

Circular segment

A = area; l = length of arc; x = angle, in degrees.

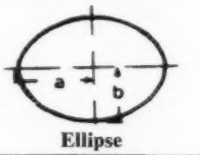
$c = 2\sqrt{h(2r - h)}$

$A = \frac{1}{2}[rl - c(r - h)]$

$l = 0.01745\ rx$

$h = r - \frac{1}{2}\sqrt{4r^2 - c^2}$

$x = \frac{57.296\,l}{r}$



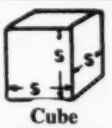
Ellipse

A = area; P = perimeter or circumference.

$A = 3.1416\ ab$.

An approximate formula for the perimeter is:

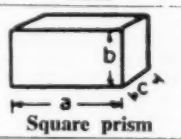
$P = 3.1416\ \sqrt{2(a^2 + b^2)}$



Cube

V = volume.

$V = s^3$



Square prism

V = volume.

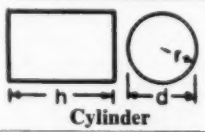
$V = abc$

$a = \frac{V}{bc}$ $\qquad b = \frac{V}{ac}$ $\qquad c = \frac{V}{ab}$

Pyramid

V = volume.

$V = \frac{1}{3}\ h \times$ area of base.



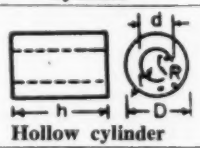
Cylinder

V = volume; S = area of curved surface.

$V = 0.7854\ d^2h$

$S = 6.2832\ rh$

Area of all surfaces is S plus twice the area of an end.

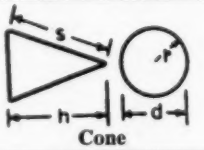


Hollow cylinder

V = volume.

$V = 0.7854\ h\ (D^2 - d^2)$

$= 3.1416\ ht\ (R + r)$



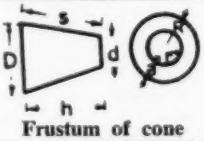
Cone

V = volume; A = area of conical surface.

$V = 0.2618\ d^2h$

$A = 1.5708\ ds$

$s = \sqrt{r^2 - h^2}$



Frustum of cone

V = volume; A = area of conical surface.

$V = 1.0472\ h\ (R^2 + Rr + r^2)$

$A = 3.1416\ s\ (R + r)$

$a = R - r$ $\qquad s = \sqrt{a^2 + h^2}$

Sphere

V = volume; A = area of surface.

$V = 0.5236\ d^3$

$A = 3.1416\ d^2$

r = 0.6204 × cube root of V

Spherical segment

V = volume; A = area of spherical surface.

$$V = 3.1416\ h^2\left(r - \frac{h}{3}\right)$$

$A = 2\pi rh$

$c = 2\sqrt{h(2r - h)}$

CIRCUMFERENCES AND AREAS OF CIRCLES FROM 1/8 TO 20

Diam.	Circum.	Area	Diam.	Circum.	Area
1/8	.3927	.012272	10	31.416	78.54
1/4	.7854	.049087	10 1/8	31.8087	80.5158
3/8	1.1781	.110447	10 1/4	32.2014	82.5161
1/2	1.5708	.19635	10 3/8	32.5941	84.5409
5/8	1.9635	.306796	10 1/2	32.9868	86.5903
3/4	2.3562	.441787	10 5/8	33.3795	88.6643
7/8	2.7489	.601322	10 3/4	33.7722	90.7628
1	3.1416	.7854	10 7/8	34.1649	92.8858
1 1/8	3.5343	.99402	11	34.5576	95.0334
1 1/4	3.927	1.2272	11 1/8	34.9503	97.2055
1 3/8	4.3197	1.4849	11 1/4	35.343	99.4022
1 1/2	4.7124	1.7671	11 3/8	35.7357	101.6234
1 5/8	5.1051	2.0739	11 1/2	36.1284	103.8691
1 3/4	5.4978	2.4053	11 5/8	36.5211	106.1394
1 7/8	5.8905	2.7612	11 3/4	36.9138	108.4343
2	6.2832	3.1416	11 7/8	37.3065	110.7537
2 1/8	6.6759	3.5466	12	37.6992	113.098
2 1/4	7.0686	3.9761	12 1/8	38.0919	115.466
2 3/8	7.4613	4.4301	12 1/4	38.4846	117.859
2 1/2	7.854	4.9087	12 3/8	38.8773	120.277
2 5/8	8.2467	5.4119	12 1/2	39.27	122.719
2 3/4	8.6394	5.9396	12 5/8	39.6627	125.185
2 7/8	9.0321	6.4918	12 3/4	40.0554	127.677
3	9.4248	7.0686	12 7/8	40.4481	130.192
3 1/8	9.8175	7.6699	13	40.8408	132.733
3 1/4	10.2102	8.2958	13 1/8	41.2335	135.297
3 3/8	10.6029	8.9462	13 1/4	41.6262	137.887
3 1/2	10.9956	9.6211	13 3/8	42.0189	140.501
3 5/8	11.3883	10.3206	13 1/2	42.4116	143.139
3 3/4	11.781	11.0447	13 5/8	42.8043	145.802
3 7/8	12.1737	11.7933	13 3/4	43.197	148.49
4	12.5664	12.5664	13 7/8	43.5897	151.202
4 1/8	12.9591	13.3641	14	43.9824	153.938
4 1/4	13.3518	14.1863	14 1/8	44.3751	156.7
4 3/8	13.7445	15.033	14 1/4	44.7678	159.485
4 1/2	14.1372	15.9043	14 3/8	45.1605	162.296
4 5/8	14.5299	16.8002	14 1/2	45.5532	165.13
4 3/4	14.9226	17.7206	14 5/8	45.9459	167.99
4 7/8	15.3153	18.6655	14 3/4	46.3386	170.874
5	15.708	19.635	14 7/8	46.7313	173.782
5 1/8	16.1007	20.629	15	47.124	176.715
5 1/4	16.4934	21.6476	15 1/8	47.5167	179.673
5 3/8	16.8861	22.6907	15 1/4	47.9094	182.655
5 1/2	17.2788	23.7583	15 3/8	48.3021	185.661
5 5/8	17.6715	24.8505	15 1/2	48.6948	188.692
5 3/4	18.0642	25.9673	15 5/8	49.0875	191.748
5 7/8	18.4569	27.1086	15 3/4	49.4802	194.828
6	18.8496	28.2744	15 7/8	49.8729	197.933
6 1/8	19.2423	29.4648	16	50.2656	201.062
6 1/4	19.635	30.6797	16 1/8	50.6583	204.216
6 3/8	20.0277	31.9191	16 1/4	51.051	207.395
6 1/2	20.4204	33.1831	16 3/8	51.4437	210.598
6 5/8	20.8131	34.4717	16 1/2	51.8364	213.825
6 3/4	21.2058	35.7848	16 5/8	52.2291	217.077
6 7/8	21.5985	37.1224	16 3/4	52.6218	220.354
7	21.9912	38.4846	16 7/8	53.0145	223.655
7 1/8	22.3839	39.8713	17	53.4072	226.981
7 1/4	22.7766	41.2826	17 1/8	53.7999	230.331
7 3/8	23.1693	42.7184	17 1/4	54.1926	233.706
7 1/2	23.562	44.1787	17 3/8	54.5853	237.105
7 5/8	23.9547	45.6636	17 1/2	54.978	240.529
7 3/4	24.3474	47.1731	17 5/8	55.3707	243.977
7 7/8	24.7401	48.7071	17 3/4	55.7634	247.45
8	25.1328	50.2656	17 7/8	56.1561	250.948
8 1/8	25.5255	51.8487	18	56.5488	254.47
8 1/4	25.9182	53.4563	18 1/8	56.9415	258.016
8 3/8	26.3109	55.0884	18 1/4	57.3342	261.587
8 1/2	26.7036	56.7451	18 3/8	57.7269	265.183
8 5/8	27.0963	58.4264	18 1/2	58.1196	268.803
8 3/4	27.489	60.1322	18 5/8	58.5123	272.448
8 7/8	27.8817	61.8625	18 3/4	58.905	276.117
9	28.2744	63.6174	18 7/8	59.2977	279.811
9 1/8	28.6671	65.3968	19	59.6904	283.529
9 1/4	29.0598	67.2008	19 1/8	60.0831	287.272
9 3/8	29.4525	69.0293	19 1/4	60.4758	291.04
9 1/2	29.8452	70.8823	19 3/8	60.8685	294.832
9 5/8	30.2379	72.7599	19 1/2	61.2612	298.648
9 3/4	30.6306	74.6621	19 5/8	61.6539	302.489
9 7/8	31.0233	76.5888	19 3/4	62.0466	306.355
			19 7/8	62.4393	310.245
			20	62.832	314.16

STANDARD TWIST DRILL SIZES

Designation	Diam, in.	Area, sq in.	Designation	Diam, in.	Area, sq in.	Designation	Diam, in.	Area, sq in.
1/2	0.5000	0.1963	3	0.213	0.03563	3/32	0.0938	0.00690
31/64	0.4844	0.1843	4	0.209	0.03431	42	0.0935	0.00687
15/32	0.4688	0.1726	5	0.2055	0.03317	43	0.0890	0.00622
29/64	0.4531	0.1613	6	0.204	0.03269	44	0.0860	0.00581
7/16	0.4375	0.1503	13/64	0.2031	0.03241	45	0.0820	0.00528
27/64	0.4219	0.1398	7	0.201	0.03173	46	0.0810	0.00515
Z	0.413	0.1340	8	0.199	0.03110	47	0.0785	0.00484
13/32	0.4063	0.1296	9	0.196	0.03017	3/64	0.0781	0.00479
Y	0.404	0.1282	10	0.1935	0.02940	48	0.0760	0.00454
X	0.397	0.1238	11	0.191	0.02865	49	0.0730	0.00419
25/64	0.3906	0.1198	12	0.189	0.02806	50	0.0700	0.00385
W	0.386	0.1170	3/16	0.1875	0.02761	51	0.0670	0.00353
V	0.377	0.1116	13	0.185	0.02688	52	0.0635	0.00317
3/8	0.375	0.1104	14	0.182	0.02602	1/16	0.0625	0.00307
U	0.368	0.1064	15	0.1800	0.02554	53	0.0595	0.00278
23/64	0.3594	0.1014	16	0.1770	0.02461	54	0.0550	0.00238
T	0.358	0.1006	17	0.1730	0.02351	55	0.0520	0.00212
S	0.348	0.09511	11/64	0.1719	0.02320	56	0.0473	0.00173
11/32	0.3438	0.09281	18	0.1695	0.02256	57	0.0465	0.001698
R	0.339	0.09026	19	0.1660	0.02164	58	0.0430	0.001452
Q	0.332	0.08657	20	0.1610	0.02036	59	0.0420	0.001385
21/64	0.3281	0.08456	21	0.1590	0.01986	60	0.0410	0.001320
P	0.323	0.08194	22	0.1570	0.01936	61	0.0400	0.001257
O	0.316	0.07843	5/32	0.1563	0.01917	62	0.039	0.001195
5/16	0.3125	0.07670	23	0.1540	0.01863	63	0.038	0.001134
N	0.302	0.07163	24	0.1520	0.01815	64	0.037	0.001075
19/64	0.2969	0.06922	25	0.1495	0.01755	65	0.036	0.001018
M	0.295	0.06835	26	0.1470	0.01697	66	0.035	0.000962
L	0.29	0.06605	27	0.1440	0.01629	67	0.033	0.000855
9/32	0.2813	0.06213	7/64	0.1406	0.01553	68	0.032	0.000804
K	0.281	0.06202	28	0.1405	0.01549	1/32	0.0313	0.000765
J	0.277	0.06026	29	0.1360	0.01453	69	0.031	0.000755
I	0.272	0.05811	30	0.1285	0.01296	70	0.0292	0.000670
H	0.266	0.05557	1/8	0.1250	0.01227	71	0.028	0.000616
17/64	0.2656	0.05542	31	0.1200	0.01131	72	0.026	0.000531
G	0.261	0.05350	32	0.1160	0.01057	73	0.025	0.000491
F	0.257	0.05187	33	0.1130	0.01003	74	0.024	0.000452
E1/4	0.2500	0.04909	34	0.1110	0.00968	75	0.0225	0.000398
D	0.246	0.04753	35	0.1100	0.00950	76	0.021	0.000346
C	0.242	0.04600	7/64	0.1094	0.00940	77	0.020	0.000314
B	0.238	0.04449	36	0.1065	0.00891	78	0.016	0.000201
15/64	0.2344	0.04314	37	0.1040	0.00849	79	0.0145	0.000165
A	0.234	0.04301	38	0.1015	0.00809	1/64	0.0156	0.000191
1	0.228	0.04083	39	0.0995	0.00778	80	0.0135	0.000143
2	0.221	0.03836	40	0.0980	0.00754			
7/32	0.2188	0.03758	41	0.0960	0.00724			

NOTE—Desigations are in fractions of an inch, in standard twist drill letters, or in standard twist drill numbers, the latter being the same as steel wire gauge numbers. *(Courtesy of AGA.)*

GAGE THICKNESS WEIGHT STEEL SHEETS

Gage	Thickness, inches	Steel weight, pounds per square foot	Galvanized Steel weight, pounds per square foot	Gage	Thickness, inches	Steel weight, pounds per square foot	Galvanized Steel weight, pounds per square foot
7	.1793	7.500	——	19	.0418	1.750	1.9062
8	.1644	6.875	——	20	.0359	1.500	1.6562
9	.1494	6.250	——	21	.0329	1.375	1.5312
10	.1345	5.625	5.7812	22	.0299	1.250	1.4062
11	.1196	5.000	5.1562	23	.0269	1.125	1.2812
12	.1046	4.375	4.5312	24	.0239	1.000	1.1562
13	.0897	3.750	3.9062	25	.0209	.875	1.0312
14	.0747	3.125	3.2812	26	.0179	.750	.9062
15	.0673	2.812	2.9687	27	.0164	.6875	.8437
16	.0598	2.500	2.6562	28	.0149	.625	.7812
17	.0538	2.250	2.4062	29	.0135	.5625	.7187
18	.0478	2.000	2.1562	30	.0120	.500	.6562

Deviation of Gases from Ideal Gas Laws

Storage cylinders, operating at relatively high pressures, are capable of offering increased storage capacity, considering the effect of deviation from the ideal gas law, to the extent of approximately 40 per cent over underground storage sands.

In the case of mixtures of gases, such as natural gas, deviation from the ideal gas law is dependent on the composition of the mixture. A method of determining this deviation for a gas of any composition and of calculating the increase in volumetric capacity under optimum operating conditions is presented.

In the compression of a gas, when working pressure exceeds approximately 50 psi gage, there is a difference between the actual volume and the volume expected as determined by the ideal gas law,

$$PV = NR'T \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where

P = pressure in pounds per square inch absolute

V = volume in cubic feet

N = number of pound-moles of gas = $\frac{\text{Weight of gas in pounds}}{\text{molecular weight}}$

R' = universal gas constant = 10.71 for cubic foot and pounds per square inch

T = temperature, absolute = 460 + °F

The difference is generally a shrinkage accompanied by a corresponding increase in density. This shrinkage, or deviation, is a function of both pressure and temperature, and reaches a maximum at the critical pressure and temperature of the gas.

Since the ideal gas law (Equation 1) has been used in the deviation of nearly all equations of state, the most convenient method for determining the pressure, volume, temperature relationships of a gas or gaseous mixture is to introduce into Equation 1 a compressibility factor Z which represents the deviation of the gas in question from the ideal gas laws and may be expressed as follows:

TABLE 1, Properties of Gases

Gas	Formula	Molecular wt.	Boiling point at atmosphere °F	Specific gravity Air = 1.00	Critical temperature °F abs.	Critical pressure psi abs.
Methane	CH_4	16.03	—259	0.553	344	673
Ethane	C_2H_6	30.05	—127	1.037	549	712
Propane	C_3H_8	44.06	— 44	1.521	666	632
Isobutane	C_4H_{10}	58.08	10	2.005	732	544
Isopentane	C_5H_{12}	72.09	82	2.488	829	482
Carbon dioxide	CO_2	44.00	—109	1.520	548	1073
Nitrogen	N_2	28.02	—320	0.970	227	492
Oxygen	O_2	32.00	—297	1.105	278	730

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$$PV = ZNR'T \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where

Z = compressibility factor

Actually, the compressibility factor Z is a dimensionless correction factor dependent on the character of the gas, the temperature, and the pressure. Values of Z have been experimentally determined[1,2*], and were found to be a function of reduced temperature, and have been plotted accordingly in Fig. 1.

The compressibility factor Z, or the deviation of a gas or a gas mixture from the ideal gas laws, is expressed in terms of reduced pressure P_r (ratio of the actual absolute pressure to the critical pressure) and of reduced temperature T_r (ratio of the actual temperature to the critical temperature), the relationship being expressed as follows:

$$P_r = P/P_c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$T_r = T/T_c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where

P = pressure in pounds per square inch absolute

T = temperature, absolute = 460 + °F

P_c = critical pressure of gas or gas mixture

T_c = critical temperature of gas or gas mixture

The critical pressure of a gas is the pressure under which the gas may exist in a gaseous state in equilibrium with its liquid at the critical temperature. The critical temperature is the temperature above which a gas cannot be liquefied by pressure alone. Values of critical constants may be obtained from critical tables and handbooks, or reference may be made to Table 1 wherein are listed properties of constituent gases.

In a gaseous mixture consisting of numerous component gases, the compressibility factor is determined by having recourse to the so-called pseudo-critical values of the mixture. The pseudo-critical pressure is the molecular average critical pressure of the gas mixture and the pseudo-critical temperature is the molecular average critical temperature of the mixture. The relationship to the critical pressure and temperature of the fundamental gases may be expressed as follows:

$$P_c = (P_c)_a N_a + (P_c)_b N_b + \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

$$T_c = (T_c)_a N_a + (T_c)_b N_b + \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

where:

N_a = Gas (a) of gas mixture as a volume fraction

N_b = Gas (b) of gas mixture as a volume fraction

P_c = Pseudo-critical pressure of gas mixture

$(P_c)_a$ = Critical pressure of N_a

$(P_c)_b$ = Critical pressure of N_b

T_c = Pseudo-critical temperature of gas mixture

$(T_c)_a$ = Critical temperature of N_a

$(T_c)_b$ = Critical temperature of N_b

TABLE 2. Various Gas Analyses.

Component	Formula	Example	Natural gas		Coke-oven gas	Producer gas: Pittsburgh coal Best	Producer gas: Pittsburgh coal Average	Producer gas: Illinois coal
Analysis number			1	2	3	4	5	6
Methane	CH_4	84.8	84.5	94.5	29.7	3.4	2.3	2.5
Ethane	C_2H_6	14.3	11.5	0.5	1.1	....	....	....
Carbon monoxide	CO	....	....	....	5.9	27.5	24.7	25.4
Hydrogen	H_2	....	....	....	57.0	12.7	15.0	11.0
Oxygen	O_2	0.2	....	0.3	....	0.2	0.2	0.1
Nitrogen	N_2	0.6	3.8	4.0	0.7	50.8	52.2	54.0
Carbon dioxide	CO_2	0.2	0.2	0.2	0.7	4.6	4.8	5.2
Ethylene	C_2H_4	....	....	0.5	3.4	0.8	0.8	0.6
Critical pressure psi abs	Pc	678.1	672.0	667.3	381.6	494.8	486.4	494.8
Critical temperature, °F abs	Tc	372.6	363.7	341.4	179.5	231.0	226.1	231.1
Reduced temperature	Tr	1.40	1.43	1.52	2.90	2.25	2.30	2.25

TABLE 3. Determination of compressibility factor and atmospheric volumetric multiplier.

Given: Critical Pressure = 678.1 psi abs.
Critical Temperature = 372.6° F abs.
Reduced Temperature = 1.396

Storage pressure Pp	Reduced pressure $Pr = \frac{Pp}{678.1}$	From Fig. 1 Zp For Tr = 1.396 For $Pr = \frac{Pp}{678.1}$	14.73Zp	Atmospheric volumetric multiplier $\frac{Pp}{14.73Zp}$
100	.147	.983	14.48	6.91
250	.369	.955	14.07	17.77
500	.737	.912	13.43	37.23
750	1.106	.871	12.83	58.46
1000	1.475	.828	12.20	81.97
1250	1.843	.790	11.64	107.39
1500	2.212	.756	11.14	134.65
1750	2.581	.736	10.84	161.44
2000	2.949	.721	10.62	188.32
2250	3.318	.718	10.58	212.67
2500	3.687	.722	10.64	234.96
2750	4.055	.733	10.80	254.63
3000	4.424	.748	11.02	272.23

In order to illustrate the determination of the compressibility factor, the following example is cited:

Example — Gas analysis, per cent by volume: Methane, 84.81; Ethane, 14.26; Nitrogen, 0.63; Carbon Dioxide, 0.15; Oxygen, 0.15. Required, the deviation for 2000 psi absolute and 60° F. The pseudo-critical pressure and temperature must be determined by means of Equations (5) and (6) and Table 1.

$$P_c = (P_c)_a N_a + (P_c)_b N_b + \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

$$P_c = 673(0.8481) + 712(0.1426) + 492(0.0063) + 1073(0.0015) + 730(0.0015) = 678.1 \text{ psi absolute}$$

$$T_c = (T_c)_a N_a + (T_c)_b N_b + \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

$$T_c = 344(0.8481) + 549(0.1426) + 227(0.0063) + 548(0.0015) + 278(0.0015) = 372.6° \text{ F absolute}$$

$$P_r = P/P_c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$P_r = \frac{2000}{678.1} = 2.949$$

$$T_r = T/T_c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

$$T_r = \frac{60 + 460}{372.6} = 1.396$$

Reduced pressure and reduced temperature are determined from Equations (3) and (4).

From Fig. 1, for $T_r = 1.395$ and $P_r = 2.949$, we find the compressibility factor $Z = 0.722$. It should be noted that if in the preceding example the gas had been at atmospheric pressure, the compressibility factor would approximate unity.

For comparative purposes Fig. 2 has been prepared based on the seven gas analyses of Table 2 giving the compressibility factor Z as a function of storage pressure and reduced temperature. Similarly, for any other gas analyses plots could be made to indicate the optimum pressure-deviation relationship. In this manner the designer of storage cylinders will be able to determine the magnitude of the increase in the storage capacity under optimum conditions. In the case of gas analysis No. 1, the best operating pressure would be 2250 psi absolute, the compressibility factor being .740.

If under standard conditions of pressure and temperature the volumetric content of a cylinder is known, the magnitude of the increase in storage capacity may be predicted based on the deviation from the ideal gas laws and the storage pressure.

$$P_a V_a = Z_a N R' T \text{ and } P_p V_p = Z_p N R' T$$

where subscripts a and p represent values at standard or atmospheric conditions and under pressure, then

$$V_a = \frac{Z_a P_p}{Z_p P_a} V_p \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

but Z_a = unity at standard conditions and $P_a = 14.73$ psi. When substituted in Equation (7) the expression in terms of standard volume will be

$$V_a = \frac{P_p}{14.73 Z_p} V_p \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

Therefore, the expression $\frac{P_p}{14.73 Z_p}$ represents a volumetric multiplier and, knowing the volume under standard conditions, the volume of gas that can be stored under operating conditions may be anticipated by multiplying the known volume by this calculated value.

Atmospheric volumetric multipliers for the seven gas analyses of Table 2 have been determined and are shown in Fig. 3, and, similarly, for any other gas analysis a plot may be established to show the expected volumetric increase for each analysis.

To further illustrate, using the gas analysis of the previous example, Table 3 shows the required calculations for the determination of the compressibility factor Z and the volumetric multiplier k for a storage pressure range of 100 psi to 3000 psi absolute.

In the foregoing discussion the probabilities of hydrate formation or liquefaction of the gas have not been taken into consideration. For any specific gas mixture these critical points should be determined for the anticipated operation conditions before proceeding with the investigation of optimum conditions of storage.

Bibliography

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2. Chemical Engineers' Handbook. By John H. Perry, McGraw-Hill Book Company, New York.

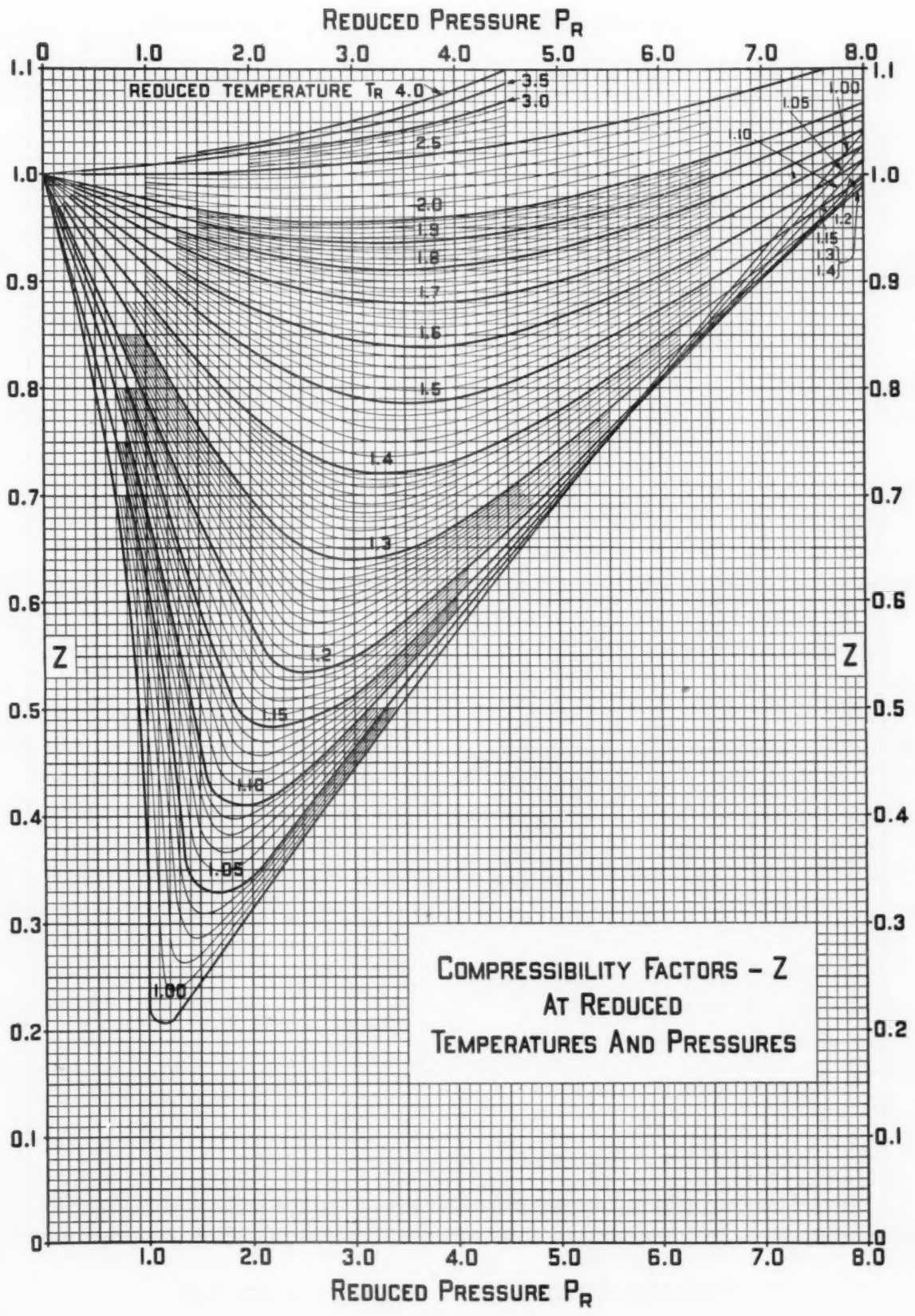

FIG. 1.

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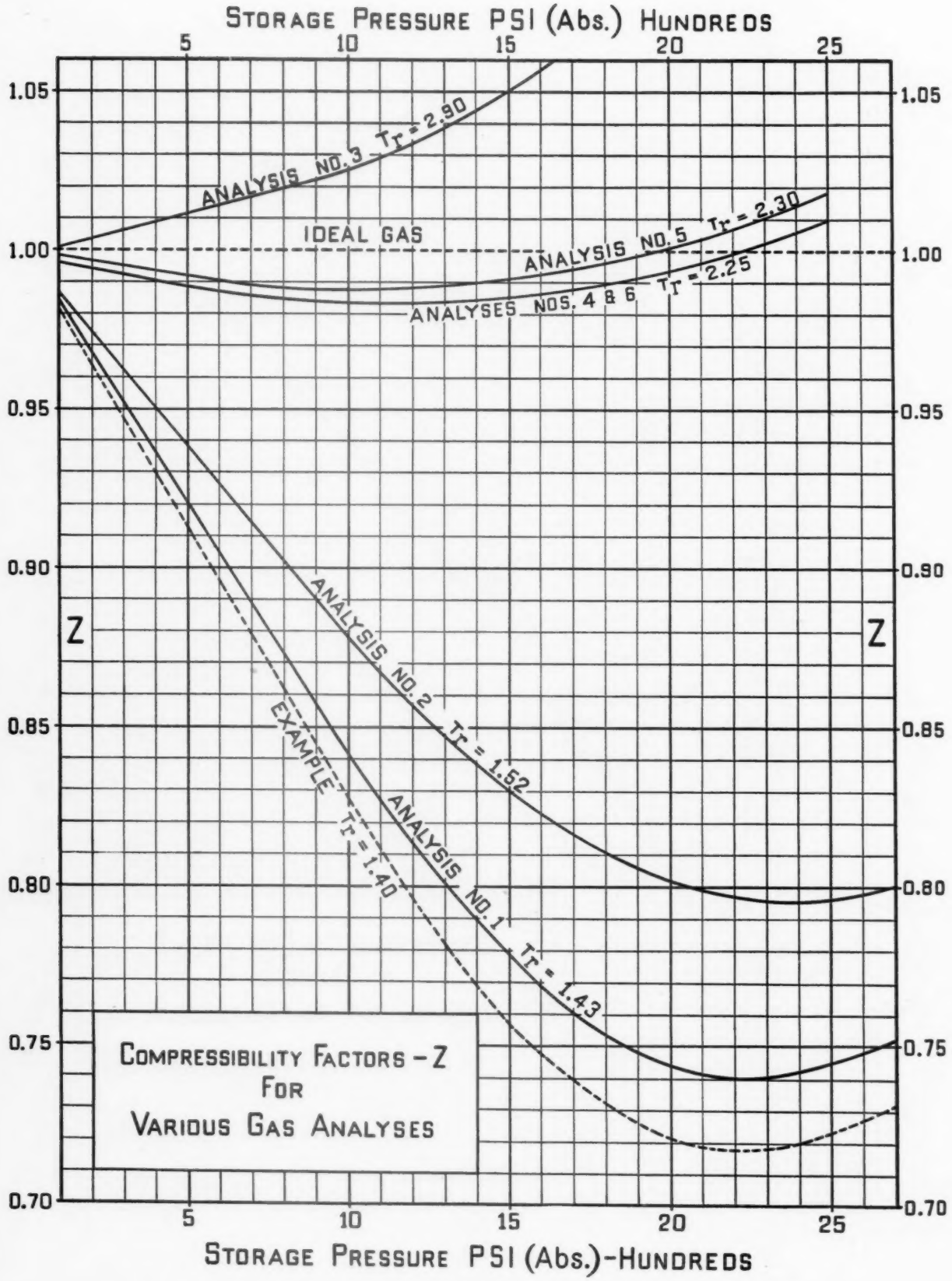
STORAGE PRESSURE PSI (Abs.) HUNDREDS
5
10
15
20
25
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
Z
ANALYSIS NO. 3 Tr = 2.90
IDEAL GAS
ANALYSIS NO. 5 Tr = 2.30
ANALYSES NOS. 4 & 6 Tr = 2.25
ANALYSIS NO. 2 Tr = 1.52
EXAMPLE Tr = 1.40
ANALYSIS NO. 1 Tr = 1.43
COMPRESSIBILITY FACTORS - Z
FOR
VARIOUS GAS ANALYSES
STORAGE PRESSURE PSI (Abs.)-HUNDREDS

FIG. 2.

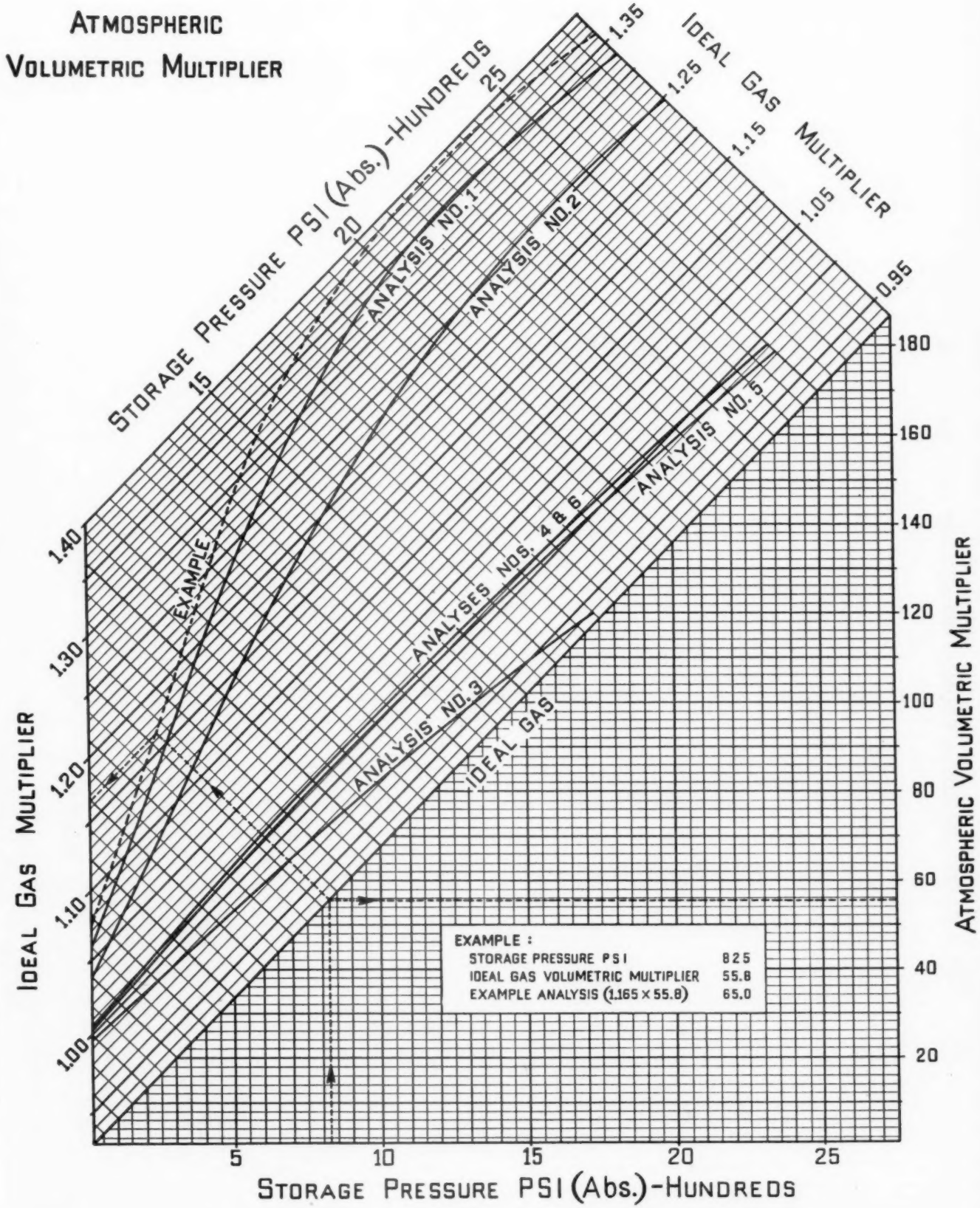
ATMOSPHERIC
VOLUMETRIC MULTIPLIER
STORAGE PRESSURE PSI (Abs.)-HUNDREDS
IDEAL GAS MULTIPLIER
ANALYSIS NO. 1
ANALYSIS NO. 2
ANALYSES NOS. 4 & 6
ANALYSIS NO. 5
ANALYSIS NO. 3
IDEAL GAS
EXAMPLE
EXAMPLE :
STORAGE PRESSURE PSI 825
IDEAL GAS VOLUMETRIC MULTIPLIER 55.8
EXAMPLE ANALYSIS (1.165 × 55.8) 65.0
IDEAL GAS MULTIPLIER
ATMOSPHERIC VOLUMETRIC MULTIPLIER
STORAGE PRESSURE PSI (Abs.)-HUNDREDS

FIG. 3.

VAPOR PRESSURES, POUNDS PER SQUARE INCH ABSOLUTE

Temperature, °F	Acetylene, C_2H_2	Ammonia, NH_3	Benzene, C_6H_6	n-Butane, C_4H_{10}	Isobutane, C_4H_{10}	Carbon Dioxide, CO_2	Carbon Disulfide, CS_2	Ethane, C_2H_6	Ethyl Alcohol, C_2H_5OH	Ethyl Chloride C_2H_5Cl	Hydrogen Sulfide, H_2S	Methyl Chloride, CH_3Cl	Naphthalene, $C_{10}H_8$		Propane, C_3H_8	Sulfur dioxide, SO_2	Toluene, C_7H_8	Water, H_2O	*m*-Xylene, C_8H_{10}
													Dry	Moist					
—20	162	18.30	....	....	7.50	215.02	0.53	158	0.022	2.16	57.5	11.75	....	....	25.4	5.883	....	....	....
—10	196	23.74	....	....	9.28	257.46	0.74	185	0.036	2.94	70.0	15.0	....	....	31.4	7.863	....	....	....
0	232	30.42	....	7.3	12.1	305.5	1.00	218	0.058	3.93	84.0	18.8	....	....	38.2	10.35	....	....	....
10	271	38.51	....	9.3	14.8	360.2	1.36	250	0.090	5.13	100	23.3	....	....	46.5	13.42	....	....	....
20	319	48.21	....	11.8	18.2	421.8	1.80	290	0.140	6.65	120	28.8	....	....	55.5	17.18	....	....	....
30	372	59.74	0.48	14.4	23.3	490.8	2.30	334	0.220	8.40	143	35.2	0.000096	0.000029	66.3	21.70	0.125	....	0.031
32	387	62.29	0.52	15.8	23.2	505.5	2.46	346	0.236	8.85	150	36.6	0.00011	0.000033	68.0	22.47	0.137	0.0887	0.034
40	430	73.32	0.66	18.4	26.9	567.8	2.96	381	0.330	10.53	169	42.6	0.00018	0.000057	78.0	27.10	0.176	0.1217	0.042
50	495	89.19	0.88	22.7	32.2	653.6	3.83	418	0.456	13.20	197	51.5	0.00034	0.00012	91.8	33.45	0.247	0.1780	0.061
60	565	107.6	1.14	27.1	38.7	748.6	4.75	496	0.640	16.5	230	61.6	0.00060	0.00026	107.1	40.93	0.335	0.2561	0.093
70	645	128.8	1.51	32.7	45.8	853.4	5.93	560	0.910	20.0	267	73.3	0.0011	0.00057	124.0	49.62	0.455	0.3628	0.131
80	735	153.0	1.95	39.0	53.9	968.7	7.30	632	1.25	24.3	302	85.3	0.0013	0.0013	142.8	59.68	0.607	0.5067	0.178
90	830	180.6	2.51	46.2	63.3	....	9.00	708	1.71	29.0	344	102.1	0.0032	0.0029	164.0	71.25	0.790	0.6980	0.241
100	..	211.9	3.20	55.0	74.7	....	10.8	...	2.32	34.9	392	118.8	0.0054	0.0054	187.0	84.52	1.03	0.9487	0.330
110	...	247.0	4.05	64.2	85.1	....	13.3	...	3.09	41.1	442	137.6	0.0088	0.0094	212.0	99.76	1.32	1.274	0.435
120	...	286.4	4.22	75	98.0	....	16.0	...	4.02	48.1	500	158.8	0.0142	0.016	240.0	120.9	1.70	1.692	0.570
130	...	329	6.41	87	112.0	....	19.0	...	5.27	56.3	560	173	0.0218	....	272	135.0	2.13	2.221	0.745
140	...	379	7.53	101	126.8	....	22.6	...	6.82	66.1	632	200	0.0322	....	....	157.8	2.70	2.887	0.978
150	...	435	9.2	115	....	....	26.5	...	8.65	76.0	700	223	0.0439	....	....	181	2.30	3.716	1.22
160	...	495	11.0	132	....	....	30.9	...	10.9	86.3	778	253	0.071	....	....	209	4.03	4.739	1.53
170	...	560	13.0	151	....	....	35.9	...	13.5	99.0	862	287	0.105	....	....	239	5.00	5.990	1.94
180	...	640	15.4	172	....	....	41.9	...	17.0	113	962	322	0.155	....	....	272	6.02	7.510	2.42
190	...	715	18.2	194	....	....	48.0	...	21.0	127	1050	360	0.217	....	....	309	7.3	9.336	2.98
200	...	800	21.7	219	....	....	55.2	...	25.5	142	1160	400	0.277	....	..	350	8.7	11.525	3.62
210	...	890	25.4	248	....	....	63.0	...	31.1	161	1280	445	0.347	....	....	399	10.3	14.123	4.42
220	...	990	....	....	....	....	71.5	..	37.8	180	....	495	0.419	....	....	449	....	17.188	5.30
230	...	1100	....	....	....	....	81.6	...	45.7	203	....	550	0.547	....	....	501	....	20.78	6.35
240	...	1210	....	....	....	....	91.8	...	54.5	230	....	605	0.68	....	....	561	....	24.97	7.55
250	...	1340	....	....	....	....	103	...	64.5	260	....	670	0.85	....	....	624	....	29.82	9.0
	d	d, h	b, d	b, c, f	c, f	d, e, f	d	d	d	d, f,	d	d, e	b, d,	b	c, f	d, f	a, d	g	d

[a] Gas Chemists Handbook, Third Edition, 1929.

[b] Gas Engineers' Handbook, First Edition, 1934.

[c] Handbook of Butane-Propane Gases, Second Edition, 1935.

[d] Handbook of Chemistry and Physics, Nineteenth Edition, 1934.

[e] *Heating and Ventilating*, September and October 1938.

[f] L. S. Marks, Mechanical Engineers' Handbook, Third Edition, 1930.

[g] J. H. Keenan, "Steam Tables and Mollier Diagram," 1930.

[h] U. S. Bur. of Standards, Circular No. 142, 1923.

Note: Over small temperature intervals the logarithm of the vapor pressure plotted against temperature is practically a straight line. For longer temperature intervals the plot against reciprocal of the absolute temperature should be used.

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WATER VAPOR IN SATURATED GAS

Per cent by volume, calculated from the gas laws

Temperature, °F.	Pressure, Pounds per Square Inch Absolute										
	50	100	150	200	250	300	350	400	500	600	700
40	0.244	0.122	0.081	0.061	0.049	0.041	0.035	0.030	0.024	0.020	0.017
50	0.356	0.178	0.119	0.089	0.071	0.059	0.051	0.055	0.036	0.030	0.025
60	0.512	0.256	0.171	0.128	0.102	0.085	0.073	0.064	0.051	0.043	0.037
70	0.726	0.363	0.242	0.181	0.145	0.121	0.104	0.091	0.073	0.061	0.052
80	1.014	0.507	0.338	0.253	0.203	0.169	0.145	0.127	0.101	0.084	0.072
90	1.396	0.698	0.465	0.349	0.279	0.233	0.199	0.174	0.140	0.116	0.100
100	1.898	0.949	0.633	0.474	0.380	0.316	0.271	0.237	0.190	0.158	0.136

From "Fuel Flue Gases." Copyright 1940. American Gas Association.

GALLONS OF WATER PER MILLION CUBIC FEET OF GAS

Pressure and temperature bases: 14.4 pounds per square inch and 60° F
Gas saturated with water vapor at indicated pressures and temperatures

Temperature, °F.	Pressure; Pounds per Square Inch Absolute										
	50	100	150	200	250	300	350	400	500	600	700
40	13.6	6.8	4.5	3.4	2.7	2.3	2.0	1.7	1.4	1.1	1.0
50	19.9	10.0	6.6	5.0	4.0	3.3	2.8	2.5	2.0	1.7	1.4
60	28.6	14.3	9.5	7.2	5.7	4.8	4.1	3.6	2.9	2.4	2.0
70	40.5	20.2	13.5	10.1	8.1	6.8	5.8	5.1	4.0	3.4	2.9
80	56.4	28.2	18.8	14.1	11.3	9.4	8.1	7.0	5.6	4.7	4.0
90	78.0	39.0	26.0	19.5	15.6	13.0	11.1	9.7	7.8	6.5	5.6
100	106.2	53.1	35.4	26.5	21.2	17.7	15.2	13.3	10.6	8.9	7.6

From "Fuel Flue Gases." Copyright 1940. American Gas Association.

VAPOR PRESSURE OF WATER

°F.	In. Hg	Lbs. per Sq. In. Absolute	°F.	In. Hg	Lbs. per Sq. In. Absolute	°F.	In. Hg	Lbs. per Sq. In. Absolute	°F.	In. Hg	Lbs. per Sq. In. Absolute
32	0.1803	0.08854	57	0.4686	0.2302	82	1.1016	0.5410	107	2.3786	1.1683
33	0.1878	0.09223	58	0.4858	0.2386	83	1.1378	0.5588	108	2.4491	1.2029
34	0.1955	0.09603	59	0.5035	0.2473	84	1.1750	0.5771	109	2.5214	1.2384
35	0.2035	0.09995	60	0.5218	0.2563	85	1.2133	0.5959	110	2.5955	1.2748
36	0.2118	0.10401	61	0.5407	0.2655	86	1.2527	0.6152	115	2.9948	1.4709
37	0.2203	0.10821	62	0.5601	0.2751	87	1.2931	0.6351	120	3.4458	1.6924
38	0.2292	0.11256	63	0.5802	0.2850	88	1.3347	0.6556	125	3.9539	1.9420
39	0.2383	0.11705	64	0.6009	0.2951	89	1.3775	0.6766	130	4.5251	2.2225
40	0.2478	0.12170	65	0.6222	0.3056	90	1.4215	0.6982	135	5.1653	2.5370
41	0.2576	0.12652	66	0.6442	0.3164	91	1.4667	0.7204	140	5.8812	2.8886
42	0.2677	0.13150	67	0.6669	0.3276	92	1.5131	0.7432	145	6.680	3.281
43	0.2782	0.13665	68	0.6903	0.3390	93	1.5608	0.7666	150	7.569	3.718
44	0.2891	0.14199	69	0.7144	0.3509	94	1.6097	0.7960	155	8.557	4.203
45	0.3004	0.14752	70	0.7392	0.3631	95	1.6600	0.8153	160	9.652	4.741
46	0.3120	0.15323	71	0.7648	0.3756	96	1.7117	0.8407	165	10.863	5.335
47	0.3240	0.15914	72	0.7912	0.3886	97	1.7647	0.8668	170	12.199	5.992
48	0.3364	0.16525	73	0.8183	0.4019	98	1.8192	0.8935	175	13.671	6.715
49	0.3493	0.17157	74	0.8462	0.4156	99	1.8751	0.9210	180	15.291	7.510
50	0.3626	0.17811	75	0.8750	0.4298	100	1.9325	0.9492	185	17.068	8.383
51	0.3764	0.18486	76	0.9046	0.4443	101	1.9915	0.9781	190	19.014	9.339
52	0.3906	0.19182	77	0.9352	0.4593	102	2.0519	1.0078	195	21.144	10.385
53	0.4052	0.19900	78	0.9666	0.4747	103	2.1138	1.0382	200	23.467	11.526
54	0.4203	0.20642	79	0.9989	0.4906	104	2.1775	1.0695	205	26.003	12.772
55	0.4359	0.2141	80	1.0321	0.5069	105	2.2429	1.1016	210	28.755	14.123
56	0.4520	0.2220	81	1.0664	0.5237	106	2.3099	1.1345	212	29.922	14.696

A special case of partial pressure is that due to vapor pressures of substances at or near their condensing conditions, especially when in the presence of some liquids. The kinetic theory has shown how separation of molecules will permit the evaporation of other gaseous molecules into the same space. All liquids exposed to an available space will partially change to vapor. The partial pressure of this vapor in the space above the liquid is given the name "vapor pressure." For each temperature of the liquid, there is a corresponding vapor pressure. When the vapor pressure equals the external pressure, the liquid is at its boiling point. For water under pressure of one atmosphere, 212° F is the temperature at which this phenomenon takes place.

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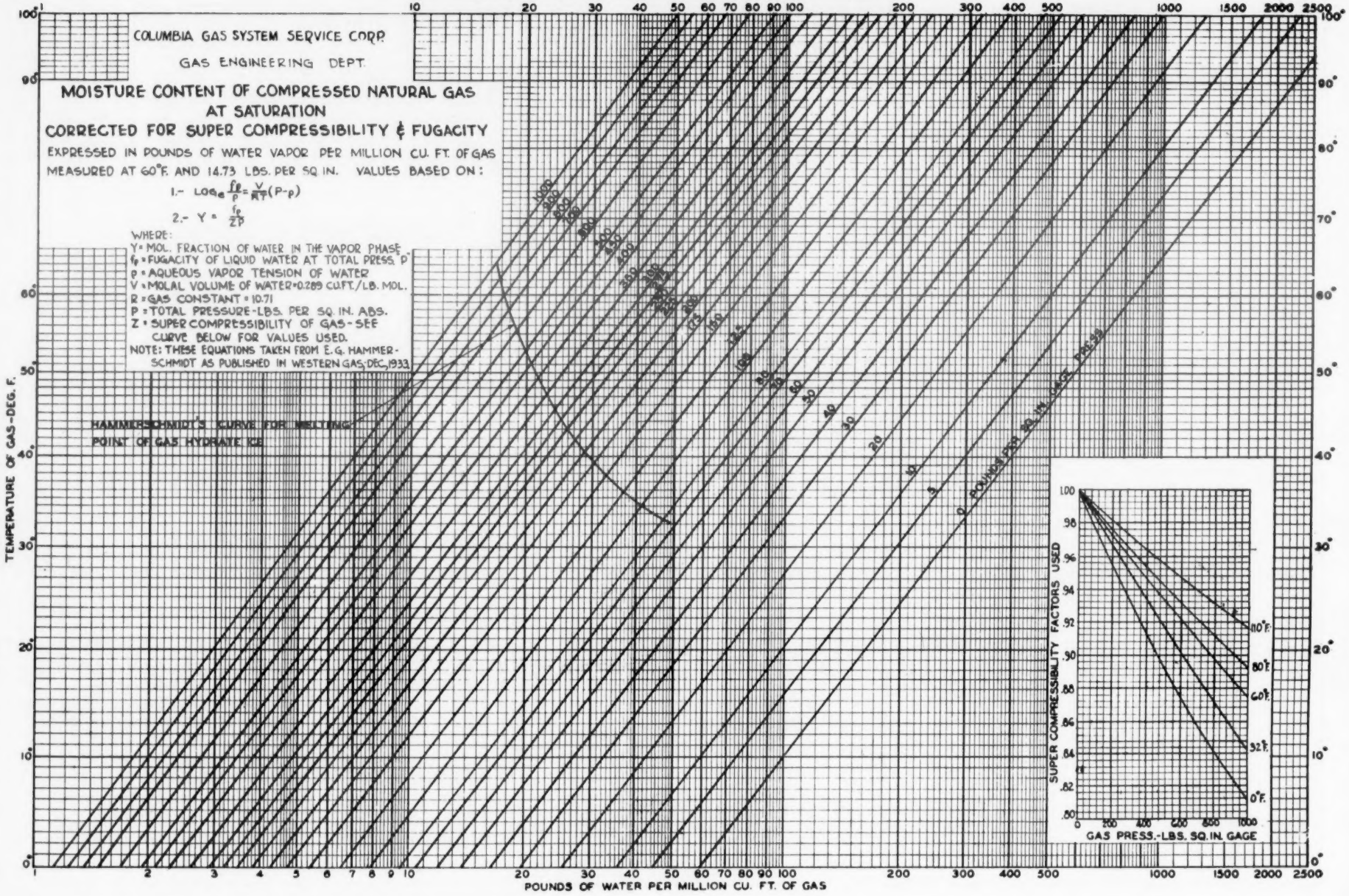
MOISTURE CONTENT OF COMPRESSED NATURAL GAS

CORRECTED FOR SUPERCOMPRESSIBILITY AND FUGACITY


COLUMBIA GAS SYSTEM SERVICE CORP.
GAS ENGINEERING DEPT.
MOISTURE CONTENT OF COMPRESSED NATURAL GAS AT SATURATION
CORRECTED FOR SUPER COMPRESSIBILITY & FUGACITY
EXPRESSED IN POUNDS OF WATER VAPOR PER MILLION CU. FT. OF GAS MEASURED AT 60°F. AND 14.73 LBS. PER SQ. IN. VALUES BASED ON:
1.- $\log_e \frac{f_p}{p} = \frac{V}{RT}(P-p)$
2.- $Y = \frac{f_p}{Zp}$
WHERE:
Y = MOL. FRACTION OF WATER IN THE VAPOR PHASE
f_p = FUGACITY OF LIQUID WATER AT TOTAL PRESS. P
p = AQUEOUS VAPOR TENSION OF WATER
V = MOLAL VOLUME OF WATER = 0.289 CU.FT./LB. MOL.
R = GAS CONSTANT = 10.71
P = TOTAL PRESSURE - LBS. PER SQ. IN. ABS.
Z = SUPER COMPRESSIBILITY OF GAS - SEE CURVE BELOW FOR VALUES USED.
NOTE: THESE EQUATIONS TAKEN FROM E.G. HAMMERSCHMIDT AS PUBLISHED IN WESTERN GAS, DEC., 1933
HAMMERSCHMIDT'S CURVE FOR MELTING POINT OF GAS HYDRATE ICE
TEMPERATURE OF GAS - DEG. F.
POUNDS OF WATER PER MILLION CU. FT. OF GAS
SUPER COMPRESSIBILITY FACTORS USED
GAS PRESS. - LBS. SQ. IN. GAGE
110°F.
80°F.
60°F.
32°F.
0°F.

N.G.A.A. VOLUME CORRECTION FACTORS (1942)

SPECIFIC GRAVITIES AT 60° F./60° F.

Observed Temperature Degrees Fahrenheit	0.500	Propane 0.5079	0.510	0.520	0.530	0.540	0.550	0.560	iso-Butane 0.5631	0.570	0.580	n-Butane 0.5844	0.590	0.600	0.610	0.620	iso-Pentane 0.6246	0.630	n-ene-tane 0.6310	0.640	0.650	0.660	0.670	0.680	0.690	0.700
	VOLUME CORRECTION FACTORS																									
—50	1.160	1.155	1.153	1.146	1.140	1.133	1.127	1.122	1.120	1.116	1.111	1.108	1.106	1.102												
—45	1.153	1.148	1.146	1.140	1.134	1.128	1.122	1.117	1.115	1.111	1.106	1.103	1.101	1.097												
—40	1.147	1.142	1.140	1.134	1.128	1.122	1.117	1.111	1.110	1.106	1.101	1.099	1.097	1.093												
—35	1.140	1.135	1.134	1.128	1.122	1.116	1.112	1.106	1.105	1.101	1.096	1.094	1.092	1.088												
—30	1.134	1.129	1.128	1.122	1.116	1.111	1.106	1.101	1.100	1.096	1.092	1.090	1.088	1.084												
—25	1.127	1.122	1.121	1.115	1.110	1.105	1.100	1.095	1.094	1.091	1.087	1.085	1.083	1.080												
—20	1.120	1.115	1.114	1.108	1.104	1.099	1.095	1.090	1.089	1.086	1.082	1.080	1.079	1.076												
—15	1.112	1.109	1.107	1.102	1.097	1.093	1.089	1.084	1.083	1.080	1.077	1.075	1.074	1.071												
—10	1.105	1.102	1.100	1.095	1.091	1.087	1.083	1.079	1.078	1.075	1.072	1.071	1.069	1.066												
— 5	1.098	1.094	1.094	1.089	1.085	1.081	1.077	1.074	1.073	1.070	1.067	1.066	1.065	1.062												
0	1.092	1.088	1.088	1.084	1.080	1.076	1.073	1.069	1.068	1.066	1.063	1.062	1.061	1.058	1.055	1.053	1.052	1.051	1.051	1.050	1.048	1.046	1.045	1.044	1.043	1.042
2	1.089	1.086	1.085	1.081	1.077	1.074	1.070	1.067	1.066	1.064	1.061	1.060	1.059	1.056	1.053	1.051	1.050	1.049	1.049	1.048	1.046	1.045	1.044	1.043	1.042	1.041
4	1.086	1.083	1.082	1.079	1.075	1.071	1.068	1.065	1.064	1.062	1.059	1.058	1.057	1.054	1.051	1.049	1.049	1.048	1.048	1.047	1.045	1.043	1.042	1.041	1.041	1.039
6	1.084	1.080	1.080	1.076	1.072	1.069	1.065	1.062	1.061	1.059	1.057	1.055	1.054	1.052	1.050	1.048	1.047	1.046	1.046	1.045	1.043	1.042	1.041	1.040	1.039	1.038
8	1.081	1.078	1.077	1.074	1.070	1.066	1.063	1.060	1.059	1.057	1.055	1.053	1.052	1.050	1.048	1.046	1.045	1.045	1.045	1.044	1.042	1.040	1.039	1.038	1.037	1.036
10	1.078	1.075	1.074	1.07.	1.067	1.064	1.061	1.058	1.057	1.055	1.053	1.051	1.050	1.048	1.046	1.044	1.044	1.043	1.043	1.042	1.040	1.039	1.038	1.037	1.036	1.035
12	1.075	1.072	1.071	1.068	1.064	1.061	1.059	1.056	1.055	1.053	1.051	1.049	1.048	1.046	1.044	1.042	1.042	1.041	1.041	1.040	1.038	1.037	1.036	1.035	1.035	1.034
14	1.072	1.070	1.069	1.066	1.062	1.059	1.056	1.053	1.053	1.051	1.049	1.047	1.046	1.044	1.042	1.041	1.040	1.039	1.039	1.038	1.037	1.036	1.035	1.034	1.033	1.032
16	1.070	1.067	1.066	1.063	1.060	1.056	1.054	1.051	1.050	1.048	1.046	1.045	1.044	1.043	1.041	1.039	1.039	1.038	1.038	1.036	1.036	1.034	1.033	1.032	1.032	1.031
18	1.067	1.065	1.064	1.061	1.057	1.054	1.051	1.049	1.048	1.046	1.044	1.043	1.042	1.041	1.039	1.038	1.037	1.036	1.036	1.035	1.034	1.033	1.032	1.031	1.030	1.029
20	1.064	1.062	1.061	1.058	1.054	1.051	1.049	1.046	1.046	1.044	1.042	1.041	1.040	1.039	1.037	1.036	1.035	1.034	1.034	1.033	1.032	1.031	1.030	1.029	1.029	1.028
22	1.061	1.059	1.058	1.055	1.052	1.049	1.046	1.044	1.044	1.042	1.040	1.039	1.038	1.036	1.035	1.034	1.033	1.032	1.032	1.031	1.030	1.030	1.029	1.028	1.028	1.027
24	1.058	1.056	1.055	1.052	1.049	1.046	1.044	1.042	1.042	1.040	1.038	1.037	1.036	1.034	1.033	1.032	1.032	1.031	1.031	1.030	1.029	1.028	1.027	1.026	1.026	1.025
26	1.055	1.053	1.052	1.049	1.047	1.044	1.042	1.039	1.039	1.037	1.036	1.036	1.034	1.033	1.032	1.031	1.030	1.029	1.029	1.028	1.027	1.027	1.026	1.025	1.024	1.024
28	1.052	1.050	1.049	1.047	1.044	1.041	1.039	1.037	1.037	1.035	1.034	1.034	1.032	1.031	1.030	1.029	1.028	1.028	1.028	1.027	1.026	1.025	1.024	1.023	1.023	1.022
30	1.049	1.047	1.046	1.044	1.041	1.039	1.037	1.035	1.035	1.033	1.032	1.032	1.030	1.029	1.028	1.027	1.027	1.026	1.026	1.025	1.024	1.024	1.023	1.022	1.022	1.021
32	1.046	1.044	1.043	1.041	1.038	1.036	1.035	1.033	1.033	1.031	1.030	1.030	1.028	1.027	1.026	1.025	1.025	1.024	1.024	1.023	1.022	1.022	1.021	1.021	1.020	1.020
34	1.043	1.041	1.040	1.038	1.036	1.034	1.032	1.031	1.030	1.029	1.028	1.028	1.026	1.025	1.024	1.023	1.023	1.022	1.022	1.022	1.021	1.021	1.020	1.019	1.019	1.018
36	1.039	1.038	1.037	1.035	1.033	1.031	1.030	1.028	1.028	1.027	1.025	1.025	1.024	1.023	1.023	1.022	1.021	1.021	1.021	1.020	1.019	1.019	1.018	1.018	1.017	1.017
38	1.036	1.035	1.034	1.032	1.031	1.029	1.027	1.026	1.025	1.025	1.023	1.023	1.022	1.021	1.021	1.020	1.020	1.019	1.019	1.019	1.018	1.018	1.017	1.016	1.016	1.015
40	1.033	1.032	1.031	1.029	1.028	1.026	1.025	1.024	1.023	1.023	1.021	1.021	1.020	1.019	1.019	1.018	1.018	1.017	1.017	1.017	1.016	1.016	1.015	1.015	1.014	1.014
42	1.030	1.029	1.028	1.027	1.025	1.024	1.023	1.022	1.021	1.021	1.019	1.019	1.018	1.018	1.017	1.016	1.016	1.015	1.015	1.015	1.014	1.014	1.013	1.013	1.013	1.013
44	1.027	1.026	1.025	1.023	1.022	1.021	1.020	1.019	1.019	1.018	1.017	1.017	1.016	1.016	1.015	1.014	1.014	1.014	1.014	1.013	1.013	1.013	1.012	1.012	1.011	1.011
46	1.023	1.022	1.022	1.021	1.020	1.018	1.018	1.017	1.016	1.016	1.015	1.015	1.014	1.014	1.013	1.013	1.013	1.012	1.012	1.012	1.011	1.011	1.010	1.010	1.010	1.010
48	1.020	1.019	1.019	1.018	1.017	1.016	1.015	1.014	1.014	1.013	1.013	1.013	1.012	1.012	1.011	1.011	1.011	1.011	1.011	1.010	1.010	1.010	1.009	1.009	1.008	1.008
50	1.017	1.016	1.016	1.015	1.014	1.013	1.013	1.012	1.012	1.011	1.011	1.011	1.010	1.010	1.009	1.009	1.009	1.009	1.009	1.008	1.008	1.008	1.007	1.007	1.007	1.007
52	1.014	1.013	1.012	1.012	1.011	1.010	1.010	1.009	1.009	1.009	1.009	1.009	1.008	1.008	1.007	1.007	1.007	1.007	1.007	1.007	1.006	1.006	1.006	1.006	1.006	1.005
54	1.010	1.010	1.009	1.009	1.008	1.008	1.007	1.007	1.007	1.007	1.006	1.006	1.006	1.006	1.006	1.005	1.005	1.005	1.005	1.005	1.005	1.005	1.004	1.004	1.004	1.004
56	1.007	1.007	1.006	1.006	1.005	1.005	1.005	1.005	1.005	1.005	1.004	1.004	1.004	1.004	1.004	1.004	1.004	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003
58	1.003	1.003	1.003	1.003	1.003	1.003	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.001	1.001	1.001	1.001
60	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
62	0.997	0.997	0.997	0.997	0.997	0.997	0.997	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.999	0.999	0.999
64	0.993	0.993	0.994	0.994	0.994	0.994	0.995	0.995	0.995	0.995	0.996	0.996	0.996	0.996	0.996	0.996	0.996	0.996	0.996	0.997	0.997	0.997	0.997	0.997	0.997	0.997
66	0.990	0.990	0.990	0.990	0.991	0.992	0.992	0.993	0.993	0.993	0.993	0.993	0.993	0.994	0.994	0.994	0.995	0.995	0.995	0.995	0.995	0.995	0.995	0.996	0.996	0.996
68	0.986	0.986	0.987	0.987	0.988	0.989	0.990	0.990	0.990	0.990	0.991	0.991	0.991	0.992	0.992	0.993	0.993	0.993	0.993	0.994	0.994	0.994	0.994	0.994	0.994	0.994
70	0.983	0.983	0.984	0.984	0.985	0.986	0.987	0.988	0.988	0.988	0.989	0.989	0.989	0.990	0.990	0.991	0.991	0.991	0.991	0.992	0.992	0.992	0.992	0.993	0.993	0.993
72	0.979	0.980	0.981	0.981	0.982	0.983	0.984	0.985	0.986	0.986	0.987	0.987	0.987	0.988	0.988	0.989	0.989	0.989	0.989	0.990	0.990	0.990	0.991	0.991	0.992	0.992
74	0.976	0.976	0.977	0.978	0.980	0.980	0.982	0.983	0.983	0.984	0.985	0.985	0.985	0.986	0.986	0.987	0.987	0.987	0.987	0.988	0.988	0.989	0.989	0.990	0.990	0.990
76	0.972	0.973	0.974	0.975	0.977	0.978	0.979	0.980	0.981	0.981	0.982	0.982	0.983	0.984	0.985	0.986	0.986	0.986	0.986	0.987	0.987	0.987	0.988	0.988	0.989	0.989
78	0.969	0.970	0.970	0.972	0.974	0.975	0.977	0.978	0.978	0.979	0.980	0.980	0.981	0.982	0.983	0.984	0.984	0.984	0.984	0.985	0.986	0.986	0.986	0.987	0.987	0.987
80	0.965	0.967	0.967	0.969	0.971	0.972	0.974	0.975	0.976	0.977	0.978	0.978	0.979	0.980	0.981	0.982	0.982	0.982	0.982	0.983	0.984	0.984	0.985	0.985	0.986	0.986
82	0.961	0.963	0.963	0.966	0.968	0.969	0.971	0.972	0.973	0.974	0.976	0.976	0.977	0.978	0.979	0.980	0.980	0.980	0.980	0.981	0.982	0.983	0.983	0.984	0.984	0.985
84	0.957	0.959	0.960	0.962	0.965	0.966	0.968	0.970	0.971	0.972	0.974	0.974	0.975	0.976	0.977	0.978	0.979	0.979	0.979	0.980	0.981	0.981	0.982	0.982	0.983	0.983
86	0.954	0.956	0.956	0.959	0.961	0.964	0.966	0.967	0.968	0.969	0.971	0.971	0.972	0.973	0.975	0.976	0.977	0.977	0.977	0.978	0.979	0.980	0.980	0.981	0.981	0.982
88	0.950	0.952	0.953	0.955	0.958	0.961	0.963	0.965	0.966	0.967	0.969	0.969	0.970	0.971	0.973	0.974	0.975	0.976	0.976	0.977	0.978	0.978	0.979	0.979	0.980	0.980
90	0.946	0.949	0.949	0.952	0.955	0.958	0.960	0.962	0.963	0.964	0.967	0.967	0.968	0.969	0.971	0.972	0.973	0.974	0.974	0.975	0.976	0.977	0.977	0.978	0.978	0.979
92	0.942	0.945	0.946	0.949	0.952	0.955	0.957	0.959	0.960	0.962	0.964	0.965	0.966	0.967	0.969	0.970	0.971	0.972	0.972	0.973	0.974	0.975	0.975	0.976	0.977	0.977
94	0.938	0.941	0.942	0.946	0.949	0.952	0.954	0.957	0.958	0.959	0.962	0.962	0.964	0.965	0.967	0.968	0.969	0.970	0.970	0.971	0.972	0.973	0.974	0.975	0.975	0.976
96	0.935	0.938	0.939	0.942	0.946	0.949	0.952	0.954	0.955	0.957	0.959	0.960	0.961	0.963	0.965	0.966	0.967	0.968	0.968	0.970	0.971	0.972	0.972	0.973	0.974	0.975
98	0.931	0.934	0.935	0.939	0.943	0.946	0.949	0.952	0.953	0.954	0.957	0.957	0.959	0.961	0.963	0.964	0.965	0.966	0.966	0.968	0.969	0.970	0.971	0.972	0.972	0.973
100	0.927	0.930	0.932	0.936	0.940	0.943	0.946	0.949	0.950	0.952	0.954	0.955	0.957	0.959	0.961	0.962	0.963	0.964	0.964	0.966	0.967	0.968	0.969	0.970	0.971	0.972
105	0.917	0.920	0.923	0.927	0.931	0.935	0.939	0.943	0.943	0.946	0.949	0.949	0.951	0.954												
110	0.907	0.911	0.913	0.918	0.923	0.927	0.932	0.936	0.937	0.939	0.943	0.944	0.946	0.949												
115	0.897	0.902	0.904	0.909	0.915	0.920	0.925	0.930	0.930	0.933	0.937	0.938	0.940	0.944												
120	0.887	0.892	0.894	0.900	0.907	0.912	0.918	0.923	0.924	0.927	0.931	0.932	0.934	0.938												
125	0.876	0.881	0.884	0.890	0.898	0.903	0.909	0.916	0.916	0.920	0.925	0.927	0.928	0.933												
130	0.865	0.871	0.873	0.880	0.888	0.895	0.901	0.908	0.909	0.913	0.918	0.921	0.923	0.927												
135	0.854	0.861	0.863	0.871	0.879	0.887	0.894	0.901	0.902	0.907	0.912	0.914	0.916	0.921												
140	0.842	0.850	0.852	0.861	0.870	0.879	0.886	0.893	0.895	0.900	0.905	0.907	0.910	0.915												

Table 2. Illustration for Use. Given the specific (60/60) 0.600 and temperature of measurement of 26° F. The volume correction factor to convert the volume at the measured temperature of 26° F to volume at 6° F is found by moving down the column headed 0.600 to intersect with the horizontal line from 26° F. The volume correction factor is 1.033.

Natural Gasoline Association of America.

N.G.A.A. SPECIFIC GRAVITY CONVERSION FACTORS (1942)

Observed Temperature Degrees Fahrenheit	OBSERVED SPECIFIC GRAVITY																															
	0.42	0.43	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.53	0.54	0.55	0.56	0.57	0.58	0.59	0.60	0.61	0.62	0.63	0.64	0.65	0.66	0.67	0.68	0.69	0.70	0.71	0.72	0.73
	CORRESPONDING SPECIFIC GRAVITIES 60° F./60° F.																															
−50																0.487	0.500	0.513	0.526	0.538	0.550	0.562	0.575	0.587	0.599							
−45																0.491	0.504	0.517	0.529	0.542	0.554	0.566	0.578	0.590								
−40															0.483	0.495	0.508	0.521	0.533	0.545	0.558	0.570	0.581	0.593								
−35															0.487	0.500	0.512	0.525	0.537	0.549	0.561	0.573	0.585	0.596								
−30															0.491	0.504	0.516	0.529	0.541	0.552	0.564	0.576	0.588	0.600								
−25															0.496	0.508	0.520	0.532	0.544	0.556	0.568	0.580	0.591									
−20														0.488	0.500	0.512	0.524	0.536	0.548	0.559	0.571	0.583	0.594									
−15														0.492	0.504	0.516	0.528	0.540	0.552	0.563	0.574	0.586	0.597									
−10													0.484	0.496	0.508	0.520	0.532	0.543	0.555	0.566	0.578	0.589	0.601									
− 5													0.488	0.500	0.512	0.524	0.536	0.547	0.559	0.570	0.581	0.593										
0												0.481	0.493	0.505	0.516	0.528	0.540	0.551	0.562	0.573	0.585	0.596	0.607	0.618	0.628	0.639	0.649	0.659	0.670	0.680	0.690	0.700
2												0.483	0.495	0.506	0.517	0.529	0.541	0.552	0.563	0.574	0.586	0.597	0.608	0.619	0.629	0.640	0.650	0.660	0.671	0.681	0.691	0.701
4												0.484	0.496	0.508	0.519	0.531	0.542	0.553	0.564	0.576	0.587	0.598	0.609	0.620	0.630	0.641	0.651	0.661	0.672	0.682	0.692	0.702
6												0.486	0.498	0.509	0.520	0.532	0.544	0.555	0.566	0.577	0.589	0.599	0.610	0.621	0.631	0.642	0.652	0.662	0.673	0.683	0.693	0.703
8												0.487	0.499	0.511	0.522	0.534	0.545	0.556	0.567	0.579	0.590	0.600	0.611	0.622	0.632	0.643	0.653	0.663	0.674	0.684	0.694	0.704
10												0.489	0.501	0.512	0.523	0.535	0.546	0.557	0.568	0.580	0.591	0.601	0.612	0.623	0.633	0.644	0.654	0.664	0.675	0.685	0.695	0.705
12												0.491	0.503	0.514	0.525	0.536	0.547	0.558	0.569	0.581	0.592	0.602	0.613	0.624	0.634	0.645	0.655	0.665	0.676	0.686	0.696	0.706
14												0.492	0.504	0.515	0.526	0.538	0.549	0.560	0.571	0.582	0.593	0.604	0.614	0.625	0.635	0.646	0.656	0.666	0.677	0.687	0.697	0.707
16												0.494	0.506	0.517	0.528	0.539	0.550	0.561	0.572	0.584	0.595	0.605	0.616	0.626	0.637	0.647	0.657	0.667	0.678	0.688	0.698	0.708
18												0.495	0.507	0.518	0.529	0.541	0.552	0.563	0.574	0.585	0.596	0.607	0.617	0.627	0.638	0.648	0.658	0.668	0.679	0.689	0.699	0.709
20											0.486	0.497	0.509	0.520	0.531	0.542	0.553	0.564	0.575	0.586	0.597	0.608	0.618	0.628	0.639	0.649	0.659	0.669	0.680	0.690	0.700	0.710
22											0.488	0.499	0.511	0.522	0.533	0.544	0.554	0.565	0.576	0.587	0.598	0.609	0.619	0.629	0.640	0.650	0.660	0.670	0.681	0.691	0.701	
24											0.490	0.501	0.512	0.523	0.534	0.545	0.556	0.567	0.578	0.588	0.599	0.610	0.620	0.630	0.641	0.651	0.661	0.671	0.682	0.692	0.702	
26											0.491	0.502	0.514	0.525	0.536	0.547	0.557	0.568	0.579	0.590	0.600	0.611	0.621	0.632	0.642	0.652	0.662	0.673	0.683	0.693	0.703	
28											0.493	0.504	0.515	0.526	0.537	0.548	0.559	0.570	0.581	0.591	0.601	0.612	0.622	0.633	0.643	0.653	0.663	0.674	0.684	0.694	0.704	
30										0.484	0.495	0.506	0.517	0.528	0.539	0.550	0.560	0.571	0.582	0.592	0.602	0.613	0.623	0.634	0.644	0.654	0.664	0.675	0.685	0.695	0.705	
32										0.486	0.497	0.508	0.519	0.530	0.540	0.551	0.561	0.572	0.583	0.593	0.603	0.614	0.624	0.635	0.645	0.655	0.665	0.676	0.686	0.696	0.706	
34										0.488	0.499	0.509	0.520	0.531	0.542	0.553	0.563	0.574	0.584	0.595	0.605	0.615	0.626	0.636	0.646	0.656	0.666	0.677	0.687	0.697	0.707	
36										0.489	0.500	0.511	0.522	0.533	0.543	0.554	0.564	0.575	0.586	0.596	0.606	0.617	0.627	0.638	0.648	0.658	0.668	0.678	0.688	0.698	0.708	
38										0.491	0.502	0.512	0.523	0.534	0.545	0.556	0.566	0.577	0.587	0.598	0.608	0.618	0.629	0.639	0.649	0.659	0.669	0.679	0.689	0.699	0.709	
40									0.483	0.493	0.504	0.514	0.525	0.536	0.546	0.557	0.567	0.578	0.588	0.599	0.609	0.619	0.630	0.640	0.650	0.660	0.670	0.680	0.690	0.700	0.710	
42									0.485	0.495	0.506	0.516	0.527	0.537	0.547	0.558	0.568	0.579	0.589	0.600	0.610	0.620	0.631	0.641	0.651	0.661	0.671	0.681	0.691	0.701		
44									0.486	0.497	0.507	0.517	0.528	0.539	0.549	0.559	0.570	0.580	0.591	0.601	0.611	0.621	0.632	0.642	0.652	0.662	0.672	0.682	0.692	0.702		
46									0.488	0.498	0.509	0.519	0.530	0.540	0.550	0.561	0.571	0.582	0.592	0.603	0.613	0.623	0.633	0.643	0.653	0.663	0.673	0.683	0.693	0.703		
48									0.489	0.500	0.510	0.520	0.531	0.542	0.552	0.562	0.573	0.583	0.594	0.604	0.614	0.624	0.634	0.644	0.654	0.664	0.674	0.684	0.694	0.704		
50								0.480	0.491	0.502	0.512	0.522	0.533	0.543	0.553	0.563	0.574	0.584	0.595	0.605	0.615	0.625	0.635	0.645	0.655	0.665	0.675	0.685	0.695	0.705		
52								0.482	0.493	0.504	0.514	0.524	0.534	0.544	0.554	0.564	0.575	0.585	0.596	0.606	0.616	0.626	0.636	0.646	0.656	0.666	0.676	0.686	0.696	0.706		
54								0.484	0.494	0.505	0.515	0.525	0.536	0.546	0.556	0.566	0.576	0.586	0.597	0.607	0.617	0.627	0.637	0.647	0.657	0.667	0.677	0.687	0.697	0.707		
56								0.486	0.496	0.507	0.517	0.527	0.537	0.547	0.557	0.567	0.578	0.588	0.598	0.608	0.618	0.628	0.638	0.648	0.658	0.668	0.678	0.688	0.698	0.708		
58								0.488	0.498	0.508	0.518	0.529	0.539	0.549	0.559	0.569	0.579	0.589	0.599	0.609	0.619	0.629	0.639	0.649	0.659	0.669	0.679	0.689	0.699	0.709		
60							0.480	0.490	0.500	0.510	0.520	0.530	0.540	0.550	0.560	0.570	0.580	0.590	0.600	0.610	0.620	0.630	0.640	0.650	0.660	0.670	0.680	0.690	0.700	0.710		
62							0.482	0.492	0.502	0.512	0.522	0.532	0.541	0.551	0.561	0.571	0.581	0.591	0.601	0.611	0.621	0.631	0.641	0.651	0.661	0.671	0.681	0.691	0.701			
64							0.484	0.494	0.504	0.513	0.523	0.533	0.543	0.553	0.563	0.573	0.582	0.592	0.602	0.612	0.622	0.632	0.642	0.652	0.662	0.672	0.682	0.692	0.702			
66							0.485	0.495	0.505	0.515	0.525	0.535	0.544	0.554	0.564	0.574	0.584	0.594	0.604	0.614	0.624	0.634	0.644	0.654	0.663	0.673	0.683	0.693	0.703			
68							0.487	0.497	0.507	0.517	0.526	0.536	0.546	0.556	0.566	0.576	0.585	0.595	0.605	0.615	0.625	0.635	0.645	0.655	0.664	0.674	0.684	0.694	0.704			
70						0.479	0.489	0.499	0.509	0.518	0.528	0.538	0.547	0.557	0.567	0.577	0.586	0.596	0.606	0.616	0.626	0.636	0.646	0.656	0.665	0.675	0.685	0.695	0.705			
72						0.481	0.491	0.501	0.511	0.520	0.529	0.539	0.548	0.558	0.568	0.578	0.587	0.597	0.607	0.617	0.627	0.637	0.647	0.657	0.666	0.676	0.686	0.696	0.706			
74						0.483	0.493	0.502	0.512	0.521	0.531	0.541	0.550	0.560	0.569	0.579	0.589	0.598	0.608	0.618	0.628	0.638	0.648	0.658	0.667	0.677	0.687	0.697	0.707			
76						0.484	0.494	0.504	0.513	0.523	0.532	0.542	0.551	0.561	0.571	0.581	0.590	0.600	0.610	0.620	0.629	0.639	0.649	0.659	0.668	0.678	0.688	0.698	0.708			
78						0.486	0.496	0.505	0.515	0.524	0.534	0.544	0.553	0.563	0.572	0.582	0.592	0.601	0.611	0.621	0.630	0.640	0.650	0.660	0.669	0.679	0.689	0.699	0.709			
80					0.479	0.488	0.498	0.507	0.517	0.526	0.535	0.545	0.554	0.564	0.573	0.583	0.592	0.602	0.612	0.622	0.631	0.641	0.651	0.661	0.670	0.680	0.690	0.700	0.710			
82					0.481	0.490	0.500	0.509	0.519	0.528	0.537	0.546	0.555	0.565	0.574	0.584	0.594	0.603	0.613	0.623	0.632	0.642	0.652	0.662	0.671	0.681	0.691	0.701				
84					0.483	0.492	0.501	0.510	0.520	0.529	0.538	0.548	0.557	0.567	0.576	0.585	0.595	0.604	0.614	0.624	0.633	0.643	0.653	0.663	0.672	0.682	0.692	0.702				
86					0.484	0.493	0.503	0.512	0.521	0.531	0.540	0.549	0.558	0.568	0.577	0.587	0.597	0.606	0.616	0.625	0.635	0.644	0.654	0.664	0.673	0.683	0.693	0.703				
88					0.486	0.495	0.504	0.513	0.523	0.532	0.541	0.551	0.560	0.569	0.579	0.588	0.598	0.607	0.617	0.626	0.636	0.645	0.655	0.665	0.674	0.684	0.694	0.704				
90				0.479	0.488	0.497	0.506	0.515	0.524	0.534	0.543	0.552	0.561	0.570	0.580	0.589	0.599	0.608	0.618	0.627	0.637	0.646	0.656	0.666	0.675	0.685	0.695	0.705				
92				0.481	0.490	0.499	0.508	0.517	0.526	0.535	0.544	0.553	0.562	0.572	0.581	0.590	0.600	0.609	0.619	0.628	0.638	0.647	0.657	0.667	0.676	0.686	0.696	0.706				
94				0.483	0.492	0.500	0.509	0.518	0.528	0.537	0.545	0.554	0.563	0.573	0.582	0.591	0.601	0.610	0.620	0.629	0.639	0.648	0.658	0.668	0.677	0.687	0.697	0.707				
96				0.484	0.493	0.502	0.511	0.520	0.529	0.538	0.547	0.556	0.565	0.574	0.584	0.593	0.602	0.612	0.621	0.630	0.640	0.649	0.659	0.669	0.678	0.688	0.698	0.708				
98				0.486	0.495	0.503	0.512	0.521	0.531	0.540	0.548	0.557	0.566	0.575	0.585	0.594	0.603	0.613	0.622	0.631	0.641	0.650	0.660	0.670	0.679	0.689	0.699	0.709				
100			0.480	0.488	0.497	0.505	0.514	0.523	0.532	0.541	0.549	0.558	0.567	0.577	0.586	0.595	0.604	0.614	0.623	0.632	0.642	0.651	0.661	0.671	0.680	0.690	0.700	0.710				
105			0.485	0.493	0.502	0.510	0.518	0.527	0.535	0.544	0.553	0.562	0.571	0.580	0.589	0.598																
110		0.481	0.489	0.497	0.506	0.514	0.522	0.530	0.539	0.548	0.557	0.565	0.574	0.583	0.592																
115		0.485	0.493	0.501	0.510	0.518	0.526	0.534	0.543	0.551	0.560	0.568	0.577	0.586	0.595																
120	0.482	0.489	0.497	0.505	0.513	0.521	0.529	0.538	0.546	0.554	0.563	0.571	0.580	0.589	0.598																
125	0.486	0.494	0.502	0.509	0.517	0.525	0.533	0.541	0.550	0.558	0.566	0.574	0.583	0.592																	
130	0.491	0.498	0.506	0.514	0.521	0.529	0.537	0.545	0.553	0.561	0.569	0.577	0.586	0.595																	
135	0.495	0.502	0.510	0.517	0.525	0.533	0.541	0.549	0.557	0.565	0.573	0.581	0.589	0.598																	
140	0.49	0.506	0.514	0.521	0.529	0.536	0.544	0.552	0.560	0.568	0.576	0.584	0.592	0.601																	

Table 1. Illustration for Use. Given the specific gravity (t/60) 0.620 at 26° F. The specific gravity 60/60 will be found by moving down the column headed 0.620 to intersect with the horizontal lines from 26° F. The specific gravity 60/60 is found to be 0.600.

Natural Gasoline Association of America.

HORSEPOWER, TORQUE, AND MOTOR SPEED CALCULATIONS

Engine Horsepower

Engine horsepower is expressed as 33,000 ft-lb of work in one minute, or 550 ft-lb in one second. The formula is:

$$ihp = \frac{mep\ LAN}{33{,}000}$$

where:

mep = mean effective pressure in psi acting on the piston.
L = length of stroke in ft.
A = area of piston in sq in.
N = number of working strokes per minute (in double acting steam engines, it is 2 × the number of revolutions).

Indicated Horsepower

The same formula is used for this calculation, except that N represents the total number of explosions per minute in all cylinders of a gas engine. In computations for four-stroke cycle, single cylinder, single acting gas engines, firing every fourth stroke, this will be the rpm divided by 2. For two-stroke, single cylinder, single-acting engines, which fire every second stroke, the value of N is represented by the rpm.

Brake Horsepower

This is the power output of the engine, measured at the flywheel or main shaft. It is the actual amount of energy delivered. It is expressed as follows:

$$bhp = \frac{T \times rpm}{5255}$$

where:

rpm = shaft speed.
T = torque in ft-lb.

Where the engine is assembled in a unit including clutch, transmission and engine accessories, power output is termed "unit horsepower."

When horsepower and shaft speed are known, torque is determined:

$$torque = \frac{hp \times 5255}{rpm}$$

Electrical Horsepower

The unit for measuring electrical horsepower input to a motor is the watt. For direct current, this is the product of volts and amperes, measured at the motor terminals, represented as: W = EI. Since 746 watts equals one electrical horsepower, then:

$$hp = \frac{EI}{746}$$

For power developed on alternating current, the following is given:

$$\text{Single phase hp} = \frac{EI \times pf}{746}$$

$$\text{Two phase hp} = \frac{2\ EI \times pf}{746}$$

$$\text{Three phase hp} = \frac{1.732\ EI \times pf}{746}$$

where:

E = average volts across terminals
I = average line current
pf = power factor expressed as decimal fraction

Motor Speed

The synchronous speed of a-c motors is determined by the number of poles and frequency:

$$\text{Synchronous speed} = \frac{120 \times f}{p}$$

where:

f = frequency in cycles
p = number of poles of the motor

Induction motors will have full load speeds of from 2 to 6 per cent less than above, averaging 4 per cent less.

Direct current motors will have standard full load speeds when hot of 575, 850, 1150, 1750, and 3500 rpm.

At normal temperature, rated load, and rated voltage, the variation above or below the above full load motor speeds may not exceed 7½ per cent in motors up to 7½-hp at 1150 rpm and 5 per cent in motors larger than 7½-hp at 1150 rpm.

The above relations are based upon the energy delivered to the motor as electrical power. The approximate horsepower delivered by the motor may be determined by multiplying the above horsepower values by the motor efficiency.

hp (delivered) = Eff. × hp (input)

Efficiencies of Electric Motors

(Average efficiencies up to 550-v in 3-phase motors)

	Induction motors		
Rating	Full load	¾ Load	½ Load
1 to 2 hp	81	79	76
3 to 5 hp	85	84	82
10 to 25 hp	87.5	87	85
25 to 50 hp	89	88.5	86.5
75 hp–100 hp	91	90	88
150–200 hp	92	91.5	89.5
Above 200 hp	93.5	93	91

	Unity P. F. Syn. Motors		
Rating	Full load	¾ Load	½ Load
25 to 50 hp	90	88.5	85
75 hp–100 hp	92	91	88
150–200 hp	93	92	89.5
Above 200 hp	94.5	93.5	92

The above are averages for 1200 and 1800 rpm motors.

Low speed motors—Efficiencies will be from 1 to 2% lower—2200-v motors 100 hp and above have approximately the same efficiency as low voltage motors. On smaller sizes the 2200-v motors have efficiencies 1 to 3% lower.

Boiler Horsepower

The equivalent evaporation of 34.5 lb of water per hour from a feed water temperature of 212 F into steam at the same temperature is a boiler horsepower.

Since the actual operating conditions of a boiler are seldom "from and at 212 F," a factor is needed to convert the rating from the actual conditions to what they would be "from and at 212 F. This is called the "factor of evaporation" and equals ratio of the heat required to generate 1 lb of steam under actual conditions to that required to make 1 lb of steam "from and at 212 F."

With small boilers in industrial plants, heat liberations of approximately 15,000 Btu per cu ft of furnace volumes per hour are attained, whereas, in large central stations, this can run up to 30,000 Btu per cu ft or higher.

The horsepower rating of a boiler is based on its heating surface, 10 sq ft heating surface being allowed per rated horsepower.

The relation between heat liberation, heating surface, per cent rating, and boiler efficiency is as follows:

$$\text{Heat liberation per hr} = \frac{\text{Heating Surface} \times 33{,}000 \times \%\ \text{Rating}}{10 \times \%\ \text{efficiency}}$$

The information on horsepower calculation, motors, steam and steam boilers is published through courtesy of "Compressed Air Data" and "Cameron Pump Data."

Water Horsepower Formulas

$$\text{Water hp} = \frac{\text{gpm} \times \text{head in feet} \times \text{specific gravity}}{3960}$$

$$\text{or Water hp} = \frac{\text{gpm} \times \text{head in psi}}{1714}$$

$$\text{Brake hp} = \frac{\text{Water hp}}{\text{Efficiency of Pump}}$$

$$\text{Kw hr per 1000 gal cold water pumped per hour} = \frac{\text{head in feet of water} \times 0.00315}{\text{efficiency of pump} \times \text{efficiency of motor}}$$

Cameron Hydraulic Data.

Power Requirements of Positive Blowers and Exhausters

$$bhp = .00474 \times D \times rpm \times P$$

Where:

bhp = horsepower required to drive the blower or exhauster
D = displacement in cu ft per revolution
rpm = revolutions per minute
P = outlet minus inlet pressure in pounds per square inch. (If inlet pressure is atmospheric, then P in the outlet gage pressure)

Note: This formula assumes a mechanical efficiency of 92 per cent for the blower or exhauster.

Volumetric efficiency is provided for since actual capacity is less than actual rpm multiplied by displacement.

Engineering Tables—Roots-Connersville.

Theoretical Compression. In compressing a gas, if the heat is removed so as to keep its temperature constant, it is called Isothermal Compression.

If all the heat of compression is retained in the gas and used to increase its temperature, it is called Adiabatic Compression.

In present-day reciprocating compressors, the air or gas is compressed very nearly adiabatically. The water-jacketing brings the compression curve somewhat below the adiabatic, but the excess pressure required to force the air or gas through the valves makes the work done very close to that which would be calculated on the assumption of adiabatic compression for the entire cylinder of air or gas.

The following formulae apply to adiabatic compression:

$$m\,e\,p = \frac{n}{n-1} P_1 \left\{ \left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right\}$$

$$i\,hp = \frac{m\,ep \times L\,A\,N}{33{,}000}$$

Where

m e p = mean effective pressure in compressor cylinder.
i h p = indicated horsepower
n = ratio of the specific heat a constant pressure to the specific heat at constant volume for air or the gas being compressed (see the table opposite).
P_1 = inlet pressure—pounds per square inch absolute.
P_2 = discharge pressure—pounds per square inch absolute.
$r = \frac{P_2}{P_1}$
L = length of stroke of compressor in feet.
A = effective area of cylinder in square inches.
N = number of strokes per minute.

For adiabatic compression of air in a single stage:

$$\left.\begin{matrix} \text{i h p per 100 cu ft} \\ \text{piston displacement} \\ \text{per min} \end{matrix}\right\} = 1.51\ P_1\ (r^{0.29} - 1)$$

Since the values of n for the principal constituents of manufactured gas do not differ substantially from that for air this formula may be applied to manufactured gas.

For natural gas (when n = 1.275) the corresponding formula would be:

$$\left.\begin{matrix} \text{i h p per 100 cu ft} \\ \text{piston displacement} \\ \text{per min} \end{matrix}\right\} = 2.023\ P_1 (r^{0.216} - 1)$$

Indicated horsepower must be divided by overall efficiency to obtain brake or delivered horsepower.

Compression Temperatures

For adiabatic compression

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} = r^{\frac{n-1}{n}}$$

Where

T_1 = absolute inlet temperature.
T_2 = absolute discharge temperature.
P_1, P_2 and r as indicated above.

Values of n for certain gases are as follows:

Acetylene	1.26
Air	1.403
Ammonia	1.310
Butane	1.108
Carbon Dioxide	1.304
Carbon Monoxide	1.404
Ethane	1.22
Ethylene	1.255
Hydrogen	1.410
Methane	1.31
Nitrogen	1.404
Oxygen	1.401
Propane	1.15
Water Vapor	1.324

Theoretical horse power required to compress 100 cu ft of air from atmospheric pressure (14.7 lb) to various gauge pressures: Adiabatic compression

Discharge Pressure lbs. gauge	H. P. Single stage	H. P. Two stage	Discharge Pressure lbs. gauge	H. P. Single stage	H. P. Two stage
5	1.9	....	80	15.9	13.7
10	3.6	....	90	16.9	14.5
15	5.0	....	100	18.0	15.4
20	6.2	....	120	19.9	16.8
25	7.4	....	140	21.6	18.0
30	8.4	....	160	....	19.1
35	9.4	....	180	....	20.1
40	10.3	....	200	....	21.0
45	11.1	....	250	....	23.0
50	11.9	....	300	....	24.7
55	12.6	....	400	....	27.6
60	13.3	....	500	....	29.8
65	14.0	....	600	....	31.7
70	14.6	12.8	...	....	....
75	15.3	13.3	...	....	....

Theoretical temperatures reached in compressing gas from atmospheric pressure (14.7 lb) and 60 F to various gauge pressures.

Discharge pressure	Discharge temperatures Single stage Mf'd gas	Discharge temperatures Single stage Natural gas	Discharge temperatures Two stage Mf'd gas	Discharge temperatures Two stage Natural gas
5	106°	94°	...	...
10	144°	121°	...	...
15	177°	145°	...	...
20	207°	166°	...	...
25	234°	184°	...	...
30	258°	201°	...	...
35	280°	216°	...	...
40	301°	230°	...	...
45	320°	243°	177°	145°
50	339°	256°	185°	150°
55	356°	267°	191°	155°
60	373°	279°	198°	160°
65	389°	289°	204°	164°
70	404°	299°	210°	168°
75	419°	308°	216°	172°
80	432°	317°	221°	176°
90	459°	334°	231°	183°
100	484°	351°	240°	189°
120	533°	379°	257°	200°
140	569°	405°	272°	211°
160	...	...	285°°	219°
180	...	...	296°	227°
200	...	...	307°	235°
250	...	...	331°	250°
300	...	...	351°	264°

Figures for manufactured gas are also applicable to air. Actual discharge temperatures will be somewhat less than the above figures because of radiation and of heat carried off by the cooling water from the cylinder jackets.

Approximate Brake Horse Power Required by Air Compressors per 100 cu ft of free air actually delivered.

Altitude feet	Single stage psig			Two stage psig			
	60	80	100	60	80	100	125
0	16.3	19.5	22.1	14.7	17.1	19.1	21.3
1000	16.1	19.2	21.7	14.5	16.8	18.7	20.9
2000	15.9	18.9	21.3	14.3	16.5	18.4	20.5
3000	15.7	18.6	20.9	14.0	16.1	18.0	20.0
4000	15.4	18.2	20.6	13.8	15.8	17.7	19.6
5000	15.2	17.9	20.3	13.5	15.5	17.3	19.2

Actual Delivery. The actual delivery of a single-stage compressor pumping to 100 lbs. gauge from atmosphere will be from 65 per cent to 80 per cent of its piston displacement, depending upon its clearance space and valve gear. A compound machine compressing to 100 lbs. gauge with an inter-cooler pressure of about 27 lbs. gauge will deliver from 80 per cent to 90 per cent of its piston displacement.

Displacement. A convenient formula for calculating the displacement of a double acting cylinder is — square of the Diameter (inches) × stroke (inches) × R. P. M. × .0009 = piston displacement (c.f.m.). This makes a reasonable allowance for the piston rod on all piston sizes from about 5″ diam. to about 30″ diam.

Data on Compression from "Compressed Air Data," Ingersoll-Rand Co.

Two Stage Compression. Two stage compression is generally used where the compression ratio r is in excess of 5 or 6. An intercooler is used between the two stages.

To secure the desired pressure with minimum work, equal work should be done in the two stages and the intermediate temperature of the gas should be reduced to that at the inlet.

Then $P_{Intermediate}$ should be $\sqrt{P_1 \times P_2}$

Also the compression ratio in each stage should equal the square root of the over-all compression ratio.

For manufactured gas (2 stage compression):

$$\left.\begin{array}{l}\text{Total i.h.p. per 100 cu.}\\ \text{ft. piston displacement}\\ \text{per min.}\end{array}\right\} 3.02P_1 (r^{0.145} - 1)$$

For natural gas (2 stage compression with n = 1.275):

$$\left.\begin{array}{l}\text{Total i.h.p. per 100 cu.}\\ \text{ft. piston displacement}\\ \text{per min.}\end{array}\right\} 4.046 (r^{0.108} - 1)$$

BRAKE HORSE POWER FORMULA

for compressing natural gas

$$BHP = \frac{R}{R + JP_2} \times \frac{5.16 \quad 124 \log. R}{0.97 - 0.03R}$$

where

BHP = brake horse power required to compress one million cu ft of natural gas per day

R = ratio of compression $= \frac{P_1}{P_2}$

P_1 = compressor discharge, psia

P_2 = compressor suction, psia

J = factor for supercompressibility (assumed .022 per 100 psia)

BHP PER MILLION CU FT OF GAS COMPRESSED

Ratio of Compression	BHP Per Million C.F. per Day		Ratio of Compression	BHP Per Million C.F. per Day		Ratio of Compression	BHP Per Million C.F. per Day	
	Natural Gas	Manufactured Gas		Natural Gas	Manufactured Gas		Natural Gas	Manufactured Gas
1.2	15.5	15.5	2.8	63.0	65.0	4.4	93.5	98.0
1.3	20.5	20.5	2.9	65.5	67.5	4.5	95.5	100.0
1.4	25.0	25.0	3.0	67.5	70.0	4.6	97.0	101.5
1.5	28.5	29.0	3.1	69.5	72.0	4.7	99.0	103.5
1.6	32.0	32.5	3.2	71.5	74.0	4.8	101.0	106.0
1.7	35.5	36.5	3.3	73.5	76.5	4.9	102.5	107.5
1.8	38.5	39.5	3.4	75.5	78.0	5.0	104.0	109.5
1.9	41.5	42.0	3.5	77.5	80.5	5.1	106.0	111.5
2.0	44.0	45.0	3.6	79.0	82.5	5.2	107.5	113.0
2.1	46.5	47.5	3.7	81.0	84.5	5.3	109.0	115.0
2.2	49.0	50.5	3.8	83.0	86.5	5.4	110.5	116.5
2.3	51.5	53.0	3.9	84.5	88.5	5.5	112.5	118.5
2.4	54.0	55.5	4.0	86.5	90.5	5.6	114.0	120.0
2.5	56.5	58.0	4.1	88.5	92.5	5.7	115.5	122.0
2.6	58.5	60.5	4.2	90.5	94.0	5.8	117.0	124.0
2.7	61.0	63.0	4.3	92.0	96.0	5.9	118.5	125.5
						6.0	120.0	127.0

Clark Bros. Company

Gas Transmission and Distribution Piping Systems

Scope and Intent

804.1 Section 8 of the American Standard Code for Pressure Piping covers the design, fabrication, installation, inspection, testing, and the safety aspects of operation and maintenance of gas transmission and distribution systems, including gas pipe lines, gas compressor stations, gas metering and regulating stations, gas mains, and gas services up to the outlet of the customer's meter set assembly. Also included within the scope of this section are gas storage equipment of the closed pipe type fabricated or forged from pipe or fabricated from pipe and fittings, and gas storage lines.

804.2 The requirements of Section 8 also cover the conditions of use of the elements of the piping systems described in 804.1, including, but not limited to, pipe, valves, fittings, flanges, bolting, gaskets, regulators, pressure vessels, pulsation dampeners, and relief valves.

804.4 The requirements of Section 8 are adequate for safety under conditions normally encountered in the gas industry. Requirements for abnormal or unusual conditions are not specifically provided for, nor are all details of engineering and construction prescribed. It is intended that all work performed within the scope of this section shall meet or exceed the safety standards expressed or implied herein.

804.5 Section 8 is concerned with: (a) Safety of the general public. (b) Employee safety to the extent that it is affected by basic design, quality of the materials and workmanship, and requirements for testing and maintenance of gas transmission and distribution facilities. Existing industrial safety regulations pertaining to work areas, safety devices, and safe work practices are not intended to be supplanted by this code.

ASA Units and Definitions

Pressure Terms

Pressure unless otherwise stated is expressed in pounds per square inch above atmospheric pressure, i.e., gauge pressure. (Abbreviation — psig)

Design pressure is the maximum operating pressure permitted by this code, as determined by the design procedures applicable to the materials and locations involved.

Maximum allowable test pressure is the maximum internal fluid pressure permitted by this code for testing for the materials and locations involved.

Maximum actual operating pressure is the maximum operating pressure existing in a piping system during a normal annual operating cycle.

Maximum allowable operatnig pressure is the maximum pressure at which a piping system may be operated in accordance with the provisions of this code. It is the pressure used in determining the setting of pressure relieving or pressure limiting devices installed to protect the system from accidental over-pressuring.

Standard service pressure is the gas pressure which a utility undertakes to maintain on its domestic customers' meters. (Sometimes called the normal utilization pressure.)

Pressure Control

Pressure relief station consists of equipment installed for the purpose of preventing the pressure on a pipe line or distribution system to which it is connected from exceeding by more than an established increment the maximum allowable operating pressure, by venting gas to the atmosphere whenever the pressure tends to rise too high. (See 805.14 and 845.71.)

Pressure limiting station consists of equipment installed for the purpose of preventing the pressure on a pipe line or distribution system from exceeding the maximum allowable operating pressure, by controlling or restricting the flow of gas when abnormal conditions develop.

Pressure regulating station consists of equipment installed for the purpose of automatically reducing and regulating the pressure in the downstream pipe line or main to which it is connected. Included are piping and auxiliary devices such as valves, control instruments, control lines, the enclosures and ventilating equipment.

Service regulator is a regulator installed on a gas service to control the pressure of the gas delivered to the customer.

Monitoring regulator is a pressure regulator set in series with another pressure regulator for the purpose of automatically taking over in an emergency the control of the pressure downstream of the station in case that pressure tends to exceed a set maximum.

Stress is the resultant internal force that resists change in the size or shape of a body acted on by external forces. In this code "stress" is often used as being synonymous with unit stress which is the stress per unit area (psi).

Operating stress is the stress in a pipe or structural member under normal operating conditions.

Hoop stress is the stress in a pipe wall, acting circumferentially in a plane perpendicular to the longitudinal axis of the pipe and produced by the pressure of the fluid in the pipe.

Maximum allowable hoop stress is the maximum hoop stress permitted by this code for the design of a piping system. It depends upon the material used, the location of the pipe, and the operating conditions.

Secondary stress is stress created in the pipe wall by loads other than internal fluid pressure. For example, backfill loads, traffic loads, beam action in a span, loads at supports and at connections to the pipe.

Nominal wall thickness (t) is the wall thickness computed by the design equation in 841.1. Under this code pipe may be ordered to this computed wall thickness without adding an allowance to compensate for the underthickness tolerances permitted in approved specifications.

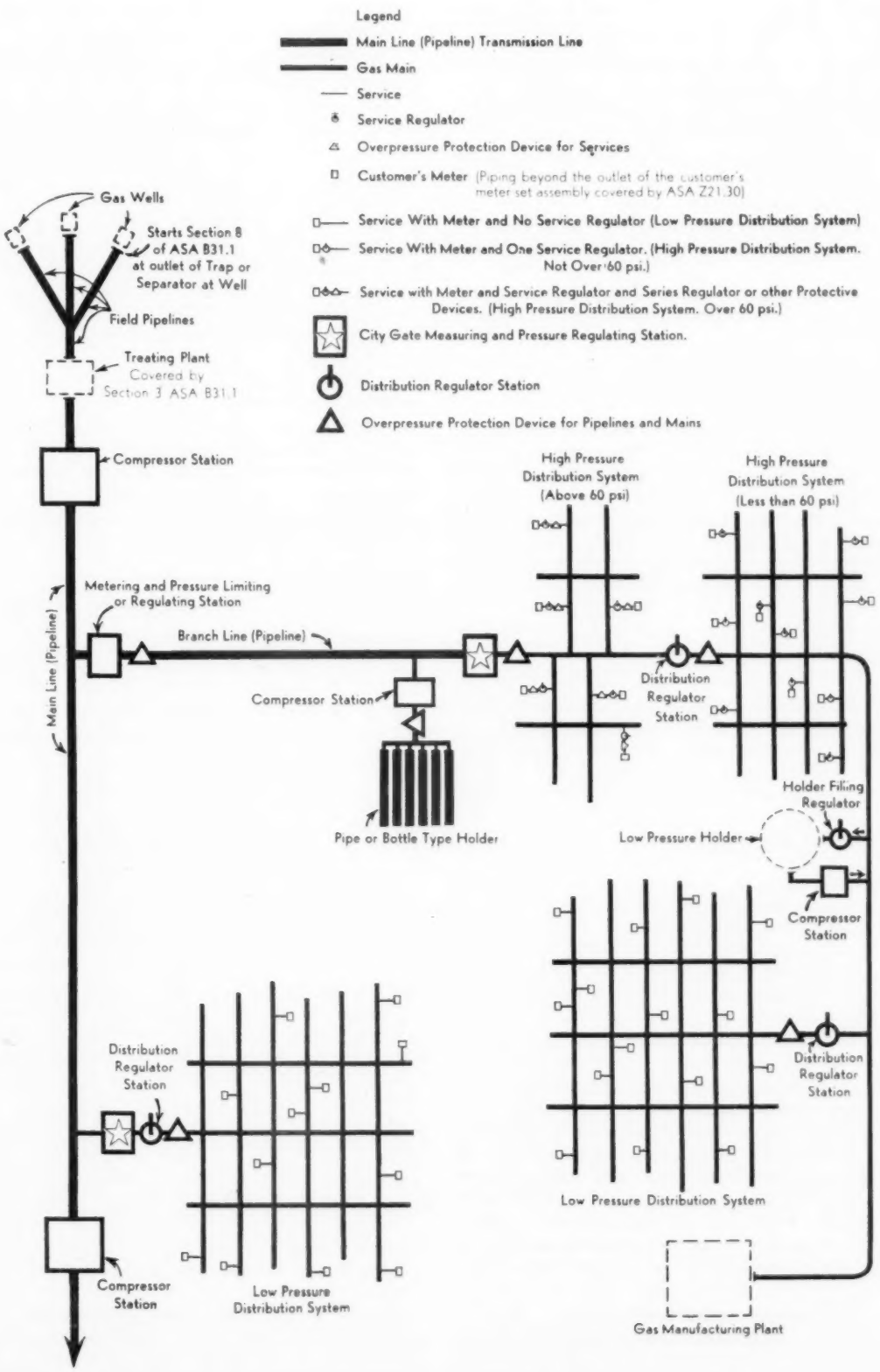
Temperatures are expressed in degrees Fahrenheit (°F.) unless otherwise stated.

Ambient temperature is the temperature of the surrounding medium, usually used to refer to the temperature of the air in which a structure is situated or a device operates.

Pages 46-58 are extracted from American Standard Gas Transmission and Distribution Piping Systems (ASA B31.1.8—1955—Section 8 of American Standard Code for Pressure Piping [ASA B31.1—1955], with the permission of the publishers, The American Society of Mechanical Engineers, 29 West 39th Street, New York 18, New York.)

DIAGRAM SHOWING SCOPE OF SECTION 8 OF ASA B31.1

Facilities indicated by Solid Lines are within the Scope of Section 8 of ASA B31.1


Legend
Main Line (Pipeline) Transmission Line
Gas Main
Service
Service Regulator
Overpressure Protection Device for Services
Customer's Meter (Piping beyond the outlet of the customer's meter set assembly covered by ASA Z21.30)
Service With Meter and No Service Regulator (Low Pressure Distribution System)
Service With Meter and One Service Regulator. (High Pressure Distribution System. Not Over 60 psi.)
Service with Meter and Service Regulator and Series Regulator or other Protective Devices. (High Pressure Distribution System. Over 60 psi.)
City Gate Measuring and Pressure Regulating Station.
Distribution Regulator Station
Overpressure Protection Device for Pipelines and Mains
Gas Wells
Starts Section 8 of ASA B31.1 at outlet of Trap or Separator at Well
Field Pipelines
Treating Plant Covered by Section 3 ASA B31.1
Compressor Station
Main Line (Pipeline)
Metering and Pressure Limiting or Regulating Station
Branch Line (Pipeline)
Compressor Station
Pipe or Bottle Type Holder
High Pressure Distribution System (Above 60 psi)
High Pressure Distribution System (Less than 60 psi)
Distribution Regulator Station
Holder Filling Regulator
Low Pressure Holder
Compressor Station
Distribution Regulator Station
Low Pressure Distribution System
Distribution Regulator Station
Compressor Station
Low Pressure Distribution System
Gas Manufacturing Plant

Ground temperature is the temperature of the earth at pipe depth.

Cold-springing where used in the code is the fabrication of piping to an actual length shorter than its nominal length; and forcing it into position, so that it is stressed in the erected condition; thus compensating partially for the effects produced by the expansion due to an increase in temperature. Cold spring factor is the ratio of the amount of cold spring provided, to the total computed temperature expansion.

Welding, Strength of Materials, and Metallurgical Terms

Yield strength is the strength at which a material exhibits a specified limiting permanent set, or produces a specified total elongation under load. The specified limiting set or elongation is usually expressed as a percentage of gauge length, and its values are specified in the various material specifications acceptable under this code.

Tensile strength is the highest unit tensile stress (referred to the original cross-section) a material can sustain before failure (psi).

Specified minimum yield strength is the minimum yield strength prescribed by the specification under which pipe is purchased from the manufacturer (psi).

Specified minimum tensile strength is the minimum tensile strength prescribed by the specification under which pipe is purchased from the manufacturer (psi).

Specified minimum elongation is the minimum elongation (expressed in per cent of the gauge length) in the tensile test specimen, prescribed by the specifications under which the material is purchased from the manufacturer.

Alloy steel. By common custom steel is considered to be alloy steel when the maximum of the range given for the content of alloying elements exceeds one or more of the following limits:

manganese	1.65%
silicon	.60%
copper	.60%

or in which a definite range or a definite minimum quantity of any of the following elements is specified or required within the limits of the recognized field of constructional alloy steels:

aluminum
boron
chromium up to 3.99%
cobalt
columbium
molybdenum
nickel
titanium
tungsten
vanadium
zirconium

or any other alloying element added to obtain a desired alloying effect.

Carbon steel. By common custom steel is considered to be carbon steel when no minimum content is specified or required for aluminum, boron, chromium, cobalt, columbium, molybdenum, nickel, titanium, tungsten, vanadium or zirconium, or any other element added to obtain a desired alloying effect; when the specified minimum for copper does not exceed 0.40 per cent; or when the maximum content specified for any of the following elements does not exceed the percentages noted: manganese 1.65, silicon 0.60, copper 0.60.

Pipe and Piping Terms

Pipe is a tubular product made as a production item for sale as such. Cylinders formed from plate in the course of the fabrication of auxiliary equipment are not pipe as defined here.

Pipe line or transmission line is a pipe installed for the purpose of transmitting gas from a source or sources of supply to one or more distribution centers or to one or more large volume customers or a pipe installed to interconnect sources of supply. In typical cases pipe lines differ from gas mains in that they operate at higher pressures, they are longer, and the distance between connections is greater.

Gas main or distribution main is a pipe installed in a community to convey gas to individual services or other mains.

Gas service is the pipe that runs between a main or a pipe line and a customer's meter.

Low-pressure distribution system is a gas distribution piping system in which the gas pressure in the mains and services is substantially the same as that delivered to the customer's appliances. In such a system a service regulator is not required on the individual services.

High-pressure distribution system is a gas distribution piping system which operates at a pressure higher than the standard service pressure delivered to the customer. In such a system a service regulator is required on each service to control the pressure delivered to the customer.

Length is a piece of pipe of the length delivered from the mill. Each piece is called a length regardless of its actual dimensions. This is sometimes called "joint" but "length" is preferred.

Cold expanded pipe is seamless or welded pipe which is formed and then expanded in the pipe mill while cold so that the circumference is permanently increased by at least .50 per cent.

Gas storage line is a pipe line used for conveying gas between a compressor station and a gas well used for storing gas underground.

Instrument piping is all piping, valves, and fittings used to connect instruments to main piping, to other instruments and apparatus, or to measuring equipment.

Control piping is all piping, valves, and fittings used to interconnect air, gas, or hydraulically operated control apparatus or instrument transmitters and receivers.

Sample piping is all piping, valves, and fittings used for the collection of samples of gas, steam, water, or oil.

Miscellaneous Terms

Private rights of way as used in this code are rights of way that are not located on roads, streets or highways used by the public, or on railroad rights of way.

Operating company as used here is the individual, partnership, corporation, public agency, or other entity that operates the gas transmission or distribution facilities.

Proprietary items are items made and marketed by a company having the exclusive right to manufacture and sell them.

Location class is a geographic area classified according to its approximate population density and its other characteristics that are considered when prescribing types of construction and methods of testing pipe lines and mains to be located in the area.

Construction type is a construction specification for pipe lines and mains that fixes the stress levels. (See Table 841.02.)

One mile population density index is a number roughly proportional to population density, applicable to a specific 1 mile length of pipe line or main and used in some cases to determine design and/or test requirements. (See 841.001.)

Ten mile population density index is a number roughly proportional to population density, applicable to a specific 10 mile length of pipe line or main and used in some cases to determine design and/or test requirements. (See 841.001.)

Gas as used in this code is any gas or mixture of gases suitable for domestic or industrial fuel and transmitted or distributed to the used through a piping system. The common

types are natural gas, manufactured gas, and liquefied petroleum gas distributed as a vapor with or without the admixture of air.

Miscellaneous Facilities

Customer's meter is a meter which measures gas delivered to a customer for consumption on his premises.

Service shut-off is a valve or cock readily accessible and operable by the customer, located in a service pipe between the gas main and the meter.

Curb shut-off is a buried valve or cock installed in a service pipe at or near the property line and accessible through a valve box and cover and operable by a removable key.

Pipe container is a gas-tight structure assembled in a shop or in the field from pipe and end closures.

Pipe-type holder is any pipe-container or group of interconnected pipe-containers installed at one location, and used for the sole purpose of storing gas.

Bottle as used in this code is a gas-tight structure completely fabricated from pipe with integral drawn, forged, or spun end closures and tested in the manufacturer's plant.

Bottle-type holder is any bottle or group of interconnected bottles installed in one location, and used for the sole purpose of storing gas.

Stop valve is a valve installed for the purpose of stopping the flow of fluid in a pipe.

Hot taps are branch piping connections made to operating pipe lines or mains or other facilities while they are in operation. The connection of the branch piping to the operating line and the tapping of the operating line is done while it is under gas pressure.

Leakage Investigation Terms

Leakage surveys are systematic surveys made for the purpose of locating leaks in a gas piping system. Three types of surveys are referred to in this code and defined below. The significant difference between the three is the manner in which the presence of a leak is first detected. They all involve verification of the presence of a leak and its location, as for example, by the driving or boring of test holes in the vicinity of the leak and testing the atmosphere in these holes with a combustible gas detector or other suitable device.

Vegetation surveys are leakage surveys made for the purpose of finding leaks in underground gas piping by observing vegetation.

Gas detector surveys are leakage surveys made by testing with a combustible gas detector the atmosphere in water meter boxes, street vaults of all types, cracks in pavements and other available locations where access to the soil under pavement is provided.

Bar test surveys are leakage surveys made by driving or boring holes at regular intervals along the route of an underground gas pipe and testing the atmosphere in the holes with a combustible gas detector or other suitable device.

Materials and Equipment

810.1 It is intended that all materials and equipment that will become a permanent part of any piping system constructed under this code shall be suitable and safe for the conditions under which they are used. All such materials and equipment shall be qualified for the conditions of their use by compliance with certain specifications, standards, and special requirements of this code or otherwise as provided herein.

Welding Inspection and Tests

828.1 *Inspection of Welds on Piping Systems Intended to Operate at Less Than 20 per cent of the Specified Minimum Yield Strength.* The quality of welding should be checked visually on a sampling basis, and if there is any reason to believe that the weld is defective, it shall be removed from the line and tested in accordance with the specification or it may be subject to a non-destructive test as outlined in 828.2.

828.2 *Inspection and Tests of Welds on Piping Systems Intended to Operate at 20 per cent or More of the Specified Minimum Yield Strength.*

(a) The quality of welding should be checked by non-destructive tests or by removing completed welds as selected and designated by the operating company. Non-destructive testing may consist of radiographic examination, magnetic particle testing, or other acceptable methods. The tre-panning method of non-destructive testing is prohibited.

(b) When radiographic examination is employed, the procedure set forth in API Standard 1104 (Standard for Field Welding of Pipe Lines) shall be followed; and the number and location of welds examined shall be at the discretion of the operating company.

(c) Completed welds which have been removed for inspection shall, to be acceptable, successfully meet the testing requirements outlined under the welder qualification procedure, and in addition, shall meet the standards of acceptability contained in 829.

829 *Standards of Acceptability of Welds on Pipe Lines Intended to Operate at 20 per cent or More of the Specified Minimum Yield Strength.* (These requirements are identical with the requirements of API 1104.)

829.1 *Inadequate Penetration and Incomplete Fusion.* Any individual inadequate penetration or incomplete fusion shall not exceed 1 inch in length. In any 12-inch length of weld, the total length of inadequate penetration or incomplete fusion shall not exceed 1 inch. The total length of the inadequate penetration or incomplete fusion in any two succeeding 12-inch lengths shall not exceed 2 inches and individual defects shall be separated by at least 6 inches of sound weld metal.

829.2. *Burn-Through Areas.* Any individual burn-through area shall not exceed ¾ inch in length. In any 12-inch length of weld, the total length of burn-through area shall not exceed 1-1½ inches. The total length of burn-through area in any two succeeding 12-inch lengths shall not exceed 3 inches, and individual defects shall be separated by at least 6 inches of sound weld metal.

829.3 *Elongated Slag Inclusions.* Any elongated slag inclusion shall not exceed 2 inches in length or 1/16 inch in width. In any 12-inch length of weld, the total length of elongated slag inclusions shall not exceed 2 inches. The total length of elongated slag inclusions in any two succeeding 12-inch lengths, shall not exceed 4 inches, and individual defects shall be separated by at least 6 inches of sound weld metal. Parallel slag lines shall be considered as individual defects if they are wider than 1/32 inch.

829.4 *Isolated Slag Inclusions.* The maximum width of any isolated slag inclusion shall not exceed ⅛ inch. In any 12-inch length of weld, the total length of isolated slag inclusions shall not exceed 1 inch, nor shall there be more than four isolated slag inclusions of the maximum width of ⅛ inch in this length. Any two such inclusions shall be separated by 2 inches of sound weld metal. In any 24-inch length of weld, the total length of isolated slag inclusions shall not exceed 2 inches.

829.5 *Gas Pockets.* The maximum dimensions of any individual gas pocket shall not exceed ⅛ inch. Maximum distribution of gas pockets shall not exceed that shown in Figures 3 and 4 of API Standard 1104.

829.6 *Cracks.* No welds containing cracks, regardless of size or location shall be acceptable until such welds have been repaired in conformance with 829.9.

829.7 *Accumulation of Discontinuities.* Any accumulation of discontinuities having a total length of more than 2

inches in a weld length of 12 inches is unacceptable. Any accumulation of discontinuities which total more than 10 per cent of the weld length of a joint is unacceptable.

829.8 *Undercutting.* Undercutting adjacent to the cover bead on the outside of the pipe shall not exceed 1/32 inch in depth and 2 inches in length. Undercutting adjacent to the root bead on the inside of the pipe shall not exceed 2 inches in length.

829.9 *Repair of Defects.*

(a) Except as provided in (g) below, defective welds shall be repaired or removed from the pipe line at the request of the company representative. The company may authorize repairs of defects in the root and filler beads, but any weld that shows evidence of repair work having been done without authorization by the company may be rejected.

(b) Minor cracks in the surface and filler beads may be repaired when so authorized by the company, but any crack penetrating the root bead or the second bead shall be cause for complete rejection of the weld. The entire weld shall be cut from the pipe line and replaced. Minor cracks shall be defined as cracks visible in the surface bead and not over 2 inches in length.

(c) Before repairs are made, injurious defects shall be removed by chipping, grinding, or oxygen gouging to clean metal. All slag and scale shall be removed by wire brushing.

(d) It is recommended that all such areas be preheated before the repair weld is started.

(e) Repaired areas shall be carefully inspected and radiographed when considered necessary.

(f) No further repairs shall be allowed in repaired areas.

(g) Repairs may be made to pin holes and undercuts in the final bead without authorization, but must meet with the approval of the company.

Piping System Components

831 All components of piping systems, including valves, flanges, fittings, headers, special assemblies, etc., shall be designed to withstand operating pressures, and other specified loadings, with unit stresses not in excess of those permitted for comparable material in pipe in the same location and type of service. Components shall be selected that are designed to withstand the field test pressure to which they will be subjected, without failure or leakage, and without impairment of their serviceability.

Design, Installation, and Testing

840.1 *General Provisions.* The design requirements of the code are intended to be adequate for public safety under all conditions usually encountered in the gas industry. However, special conditions that may cause additional stress in any part of a line or its appurtenances shall be provided for, using good engineering practice. Examples of such special conditions include: long self-supported spans, unstable ground, mechanical or sonic vibrations, weight of special attachments, and thermal forces other than seasonal.

Steel Pipe

841.001 *Population Density Indices*

(a) Two population density indices, determined at the time of initial construction, are used to classify locations for design and testing purposes: (1) the one-mile density index, which applies to any specific mile of pipe line; and (2) the ten-mile density index, which applies to any specific ten-mile length of pipe line.

(b) To determine the one-mile density indices for a proposed pipe line, lay out a zone one-half mile wide along the route of the pipe line with the pipe line on the center line of this zone. Divide the zone into lengths, each containing one mile of pipe line. Count the number of buildings intended for human occupancy in each of these lengths. These numbers are the one-mile indices for the pipe line.

(c) To determine the ten-mile density indices for any given ten-mile length of pipe line, proceed as follows: Add the one-mile density indices for the ten-mile section. In case a one-mile index equals or exceeds 20, it is to be included in the sum as 20. Divide the sum thus obtained by 10. The quotient is the ten-mile density index for the section.

Classification of Locations

841.011 *Class 1 Locations.* Class 1 locations include waste lands, deserts, rugged mountains, grazing land, and farm land, and combinations of these; provided, however, that:

(a) The ten-mile density index for any section of the line is 12 or less.

(b) The one-mile density index for any one mile of line is 20 or less. See Note (1).

841.012 *Class 2 Locations.* Class 2 locations include areas where the degree of development is intermediate between Class 1 locations and Class 3 locations. Fringe areas around cities and towns, and farm or industrial areas where the one-mile density index exceeds 20 or the ten-mile density index exceeds 12 fall within this location class.

Note (1): It is not intended that a full mile of lower-stress-level pipe line shall be installed if there are physical barriers or other factors that will limit the further expansion of the more densely populated area to a total distance of less than 1 mile. It is intended, however, that where no such barriers exist, ample allowance shall be made in determining the limits of the lower-stress design to provide for probable further development in the area.

841.013 *Class 3 Locations.* Class 3 locations include areas subdivided for residential or commercial purposes where, at the time of construction of the pipe line or piping system, 10 per cent or more of the lots abutting on the street or right-of-way in which the pipe is to be located are built upon, and a Class 4 classification is not called for. This permits classifying as Class 3, areas completely occupied by commercial or residential buildings with the prevalent height of three stories or less.

841.014 *Class 4 Locations.* Class 4 locations include areas where multistory[1] buildings are prevalent, and where traffic is heavy or dense and where there may be numerous other utilities underground.

841.015 It should be emphasized that *Location Class* (1, 2, 3 or 4), as described in the foregoing paragraphs, is defined as the general description of a geographic area having certain characteristics as a basis for prescribing the types of construction and methods of testing to be used in those locations or in areas that are respectively comparable. A numbered Location-Class refers only to the geography of that location or a similar area, and does not necessarily indicate that a correspondingly numbered Construction-Type will suffice for all construction in that particular location or area. Example: In Locating Class 1, all aerial crossings require Type B construction. (See 841.143)

841.016 When classifying locations for the purpose of determining the type of pipe line construction and testing that should be prescribed, due consideration shall be given to the possibility of future development of the area. If at the time of planning a new pipe line this future development appears likely to be sufficient to change the location class, this should be taken into consideration in the design and testing of the proposed pipe line.

It is also anticipated that some increase in population density will occur in all areas after a line is constructed, and this possibility has been taken into account in establishing the design, construction, and testing procedures for each location class.

Note (1): Multistory means 4 or more "floors" above ground including the first or ground floor. The depth of basements or number of basement floors is immaterial.

841.1 *Steel Pipe Design Formula.* The design pressure for steel piping systems or the normal wall thickness for a given design pressure shall be determined by the following formula:

$$P = \frac{2St}{D} \times F \times E \times T$$

(For exceptions see 841.4)

Where:

P = Design pressure, psig

S = Specified minimum yield strength, psi, stipulated in the specifications under which the pipe was purchased from the manufacturer or determined in accordance with 811.27 H. The specified minimum yield strengths of some of the more commonly used piping steels, whose specifications are incorporated by reference herein, are tabulated for convenience in Appendix "C". For special limitation on S see 841.14 (e) and (f).

D = Nominal outside diameter of pipe, inches.

t = Nominal wall thickness, inches.

F = Construction type design factor obtained from 841.11.

E = Longitudinal joint factor obtained from 841.12.

T = Temperature derating factor obtained from Table 841.13.

Table 841.11
Values of Design Factor "F"

Construction Type (See 841.02)	*Design Factor F*
Type — A	0.72
Type — B	0.60
Type — C	0.50
Type — D	0.40

Table*841.12
Longitudinal Joint Factor "E"

Spec. Number	*Pipe Type*	*E Factor*
ASTM A53	Seamless	1.00
	Electric Resistance Welded	1.00
	Furnace Lap Welded	.80
	Furnace Butt Welded	.60
ASTM A106	Seamless	1.00
ASTM A134	Electric Fusion Welded	.80
ASTM A135	Electric Resistance Welded	1.00
ASTM A139	Electric Fusion Welded	.80
ASTM A155	Electric Fusion Welded	1.00
API 5L	Seamless	1.00
	Electric Resistance Welded	1.00
	Electric Flash Welded	1.00
	Furnace Lap Welded	.80
	Furnace Butt Welded	.60
API 5LX	Seamless	1.00
	Electric Resistance Welded	1.00
	Electric Flash Welded	1.00
	Submerged Arc Welded	1.00

Table 841.13
Temperature Derating Factor "T" For Steel Pipe

Temperature Degrees Fahrenheit	*Temperature Derating Factor "T"*
200° F. or less	1.000
300° F.	0.967
350° F.	0.933
400° F.	0.900
450° F.	0.867

NOTE: For intermediate temperatures interpolate for derating factor.

CONSTRUCTION TYPES REQUIRED FOR PARALLEL ENCROACHMENTS OF PIPELINES AND MAINS ON ROADS AND RAILROADS

Kind of Thoroughfare	Construction Type Required			
	Location class 1	Location class 2	Location class 3	Location class 4
(a) Privately owned roads	Type A	Type B	Type C	Type D
(b) Unimproved public roads	Type A	Type B	Type C	Type D
(c) Hard surface roads, highways or public streets and railroads	Type B	Type B	Type C	Type D

CONSTRUCTION TYPES REQUIRED FOR PIPELINES AND MAINS CROSSING ROADS AND RAILROADS

Kind of Thoroughfare	Construction Type Required			
	Location class 1	Location class 2	Location class 3	Location class 4
(a) Privately owned roads	Type A without casing	Type B without casing	Type C without casing	Type D without casing
(b) Unimproved public roads	Type A with casing Type B without casing	Type B without casing	Type C without casing	Type D without casing
(c) Hard surface roads, highways or public streets and railroads	Type A with casing Type B without casing	Type B with casing Type B without casing	Type C without casing	Type D without casing

CLASSIFICATION OF STEEL PIPE CONSTRUCTION[1]

Four types of steel pipe construction are prescribed in this code. The distinguishing characteristics of each type and the locations in which each type shall be used are as follows:

A. Characteristics	Type A construction	Type B construction	Type C construction	Type D construction
1. Design Factor F (See 841.11)	.72	.60	.50	.40
B. Locations where type of construction shall be used.	(a) On private rights of way in class 1 locations. (b) Parallel encroachments on: Privately owned roads in class 1 locations. Unimproved roads in class 1 locations. (c) Crossings without casings of privately owned roads in class 1 locations. (d) Crossings in casings of unimproved public roads hard-surfaced roads highways or public streets and railroads in class 1 locations.	(a) On private rights of way in class 2 locations. (b) Parallel encroachments on: Privately owned roads in class 2 locations. Unimproved public roads in class 2 locations. Hard surfaced roads, highways or public streets and railroads in class 1 locations. (c) Crossings without casings of: Privately owned roads in class 2 locations. Unimproved public roads in class 2 locations. Hard surfaced roads, highways or public streets and railroads in class 1 and class 2 locations. (d) Crossings in casings of: Hard surfaced roads, highways or public streets and railroads in class 2 locations. (e) On bridges in class 1 and class 2 locations. (See 841.143) (f) Fabricated assemblies in pipe lines in location classes 1 and 2. (See 841.142)	(a) On private rights of way in class 3 locations. (b) Parallel encroachments on: Privately owned roads in class 3 locations. Unimproved public roads in class 3 locations. Hard surfaced roads, highways or public streets and railroads in class 3 locations. (c) Crossings without casings of: Privately owned roads in class 3 locations. Unimproved public roads in class 3 locations. Hard surfaced roads, highways or public streets and railroads in class 2 and 3 locations. (d) Compressor station piping.	(a) In all locations in location class 4.

(1) It is necessary to distinguish between construction types, as defined by Section A of this table, and location classes, as defined in 841.01, to avoid confusion. If pipelines or mains are located in private rights of way, the code prescribes that Type A construction be used in Class 1 locations, Type B construction in Class 2 locations, Type C construction in Class 3 locations, and Type D construction in Class 4 locations. There are many exceptions to this association of Class 1 with Type A, etc., however, as Table 841.02 shows, most of which are cases where pipelines or mains are located in highways or on bridges, etc.

Operating and Maintenance Procedures

850 **Operating and Maintenance Procedures affecting the safety of gas transmission and distribution facilities**

850.1 Because of many variables, it is not possible to prescribe in a national code a set of operating and maintenance procedures that will be adequate from the standpoint of public safety in all cases without being burdensome and impractical in some.

850.2 It is possible, however, for each operating company to develop operating and maintenance procedures based on experience, knowledge of its facilities and conditions under which they are operated, which will be entirely adequate from the standpoint of public safety.

850.3 **Basic Requirement.** Each operating company having gas transmission or distribution facilities within the scope of this code shall:

(a) Have a plan covering operating and maintenance procedures in accordance with the purpose of this code.

(b) Operate and maintain its facilities in conformance with this plan.

(c) Keep records necessary to administer the plan properly.

(d) Modify the plan from time to time as experience with it dictates and as exposure of the public to the facilities and changes in operating conditions require.

850.4 **Essential Features of the Plan.** The plan prescribed in 850.3 (a) above should include:

(a) Detailed plans and instructions to employees covering operating and maintenance procedures for gas facilities during normal operations and repairs, and during emergencies.

(b) Items recommended for inclusion in the plan for specific classes of facilities are given in 851 to 857, inclusive.

(c) Particular attention should be given to those portions of the facilities presenting the greatest hazard to the public in the event of an emergency or because of construction or extraordinary maintenance requirements.

852 **Distribution Piping Maintenance**

852.1 **Patrolling.** Distribution mains, which are installed in locations or on structures where abnormal physical movement or abnormal external loading could cause failure or leakage, shall be patrolled periodically and the frequency of the patrolling shall be determined by the severity of the conditions which could cause failure or leakage and the consequent hazards to public safety.

852.2 **Leakage Surveys and Routine Procedures**

852.21 Each operating company having a gas distribution system shall set up in its operating and maintenance plan a provision for the making of periodic leakage surveys. The types of surveys prescribed in the plan shall be one or more of the following employed singly or in combination, or some other effective procedure for locating leaks in underground piping systems.

(a) Gas detector surveys.

(b) Bar test surveys.

(c) Vegetation surveys.

(d) Pressure drop surveys.

(e) Soapsuds testing on exposed pipe and fittings.

852.22 The nature of the operations and local conditions of each individual company shall determine the type and scope of the leakage control program most suitable. The character of the general service area together with housing concentration should determine the frequency of the inspection program.

It is recommended that the inspection program should include at least the following provisions:

(a) At least once a year a gas detector survey should be conducted in business districts, involving tests of the atmosphere in gas, electric, telephone, sewer and water system manholes, at cracks in pavement and sidewalks and at other locations providing an opportunity for finding gas leaks. Leakage surveys, using one or more of the types referred to in 852.21, should be made of the distribution system outside of the principal business areas as frequently as experience indicates that they are necessary but not less than once every five years.

(b) Leaks located by these surveys shall be investigated promptly and any necessary repairs shall be made. When the condition of a main or a service, as indicated by leak frequency records or visual observation, deteriorates to the point where it should not be retained in service, it should be replaced or reconditioned.

852.3 **Abandoning Inactive Service and Mains**

Each operating company shall have a plan in its operation and maintenance procedures for sealing off the supply of gas to all abandoned services and mains by means of valves or other effective methods. This plan shall include procedures for abandoning services that have remained inactive for a period of years and for which there is no planned use. It is recommended that the plan include the following provisions:

854 **Procedures for Maintaining Pipe-Type and Bottle-Type Holders in Safe Operating Condition**

854.1 Each operating company having a pipe-type or bottle-type holder shall prepare and place in its files a plan for the systematic, routine inspection and testing of the facilities which provides that:

854.11 Procedures shall be followed to enable the detection of external corrosion before the strength of the container has been impaired.

854.12 Periodic sampling and testing of gas in storage will

be made to determine the dew point of vapors contained in the stored gas that might cause internal corrosion or interfere with the safe operations of the storage plant.

854.13 The pressure control and pressure limiting equipment will be inspected and tested periodically to see if it is in a safe operating condition and has adequate capacity.

854.2 Each operating company, having prepared such a plan as described in 854.1 above, shall follow the plan, and keep records which detail the inspection and testing work done and the conditions found.

854.3 All unsatisfactory conditions found shall be promptly corrected.

855 **Maintenance of Pressure Limiting and Pressure Regulating Stations**

855.1 All pressure limiting stations, relief devices, and pressure regulating stations and equipment shall be subjected to systematic periodic inspections and/or tests to determine that they are:

(a) In good mechanical condition.

(b) Adequate from the standpoint of capacity and reliability of operation for the service in which they are employed.

(c) Set to function at the correct pressure.

(d) Properly installed and protected from dirt, liquids, or other conditions that might prevent proper opeation.

855.2 (a) Every distribution system supplied by more than one district pressure regulating station shall be equipped with telemetering or recording pressure gauges to indicate the gas pressure in the district.

(b) On distribution systems supplied by a single district pressure regulating station the operating company shall determine the necessity of installing such gauges in the district. In making this determination the operating company shall take into consideration the operating conditions such as the number of customers supplied, the operating pressures, and the capacity of the installation, etc.

(c) If there are indications of abnormal high or low pressure the regulator and the auxiliary equipment shall be inspected and the necessary measures shall be employed to rectify any unsatisfactory operating conditions. Suitable periodic inspections of single district pressure regulation stations not equipped with telemetering or recording gauges shall be made to determine that the pressure regulating equipment is functioning properly.

855.3 Whenever it is practicable to do so, pressure relief valves should be tested in place to determine that they have sufficient capacity to limit the pressure on the facilities to which they are connected to the desired maximum pressure. If such tests are not feasible, periodic review and calculation of the required capacity of the relieving equipment at each station should be made and these required capacities compared with the rated or experimentally determined relieving capacity of the installed equipment for the operating conditions under which it works. If it is determined that the relieving equipment is of insufficient capacity, steps shall be taken to install new or additional equipment to provide capacity.

856 **Valve Maintenance**

856.1 **Pipeline Valves** that might be required during an emergency shall be inspected periodically and partially operated at least once per year to provide safe and proper operating conditions.

856.2 **Distribution System Valves.** Valves, the use of which may be necessary for the safe operation of a gas distribution system, shall be checked and serviced, including lubrication where necessary, at sufficiently frequent intervals to be reasonably assured of their satisfactory operation. Inspection shall include checking of alignment to permit use of a key or wrench and clearing from the valve box or vault any debris which would interfere with or delay the operation of the valve.

857 **Vault Maintenance.** Regularly scheduled inspections shall be made of each vault housing pressure regulating and pressure limiting equipment and having a volumetric internal content of 200 cubic feet or more to determine if it is in good physical condition and adequately vented. This inspection shall include the testing of the atmosphere in the vault atmosphere, the equipment in the vault shall be inspected for leaks and leaks found shall be repaired. The ventilating equipment shall also be inspected to determine if it is functioning properly. If the ventilating ducts are obstructed, they shall be cleared. The condition of the vault covers shall be carefully examined to see that they do not present a hazard to public safety.

Miscellaneous

860 **Miscellaneous**

861 **Odorization.** Any gas, distributed to consumers through gas mains or gas services or used for domestic purposes in compressor plants, which does not naturally possess a distinctive odor to the extent that its presence in the atmosphere is readily detectable at concentrations well below that required to produce an explosive mixture shall have an odorant added to it to make it so detectable. Odorization is not necessary, however, for such gas as is delivered for further processing or use where the odorant would serve no useful purpose as a warning agent.

862 **Liquefied Petroleum Gas (LPG) Systems.**

862.1 Liquefied petroleum gases, generally, include butane and propane, and mixtures of them that can be stored as liquids under moderate pressures (approximately 80 psig to 250 psig) at ambient temperatures.

862. This code is concerned only with certain safety aspects of liquefied petroleum gases when they are vaporized and used as gaseous fuels.

862.3 All of the requirements of Standards No. 58 and No. 59 of the National Board of Fire Underwriters and the National Fire Protection Association and of this code, concerning design, construction, and operation and maintenance of piping facilities shall apply to piping systems handling butane, propane, or mixtures of these gases.

862.4 **Special Safety Requirements for LPG Systems**

862.41 **Odorization.** Liquefied petroleum gases are usually nontoxic, but for safety when distributed for consumer use, or used as fuel in a place of employment, they shall be odorized. Criteria for odorization are given in 861. See note (1)

862.42 **Ventilation**

(a) All liquefied petroleum gases are heavier than air, hence structures above ground for housing regulators, meters, etc., shall have open vents near the floor level. Such equipment shall not be installed in pits or in underground vaults, except in cases where suitable provisions for forced ventilation are made.

(b) Special care is required in the location of relief valve discharge vents releasing LPG to the atmosphere, to prevent accumulation of the heavy gases at or below ground level. Likewise, special precautions are necessary for adequate ventilation where excavations are made for the repair of leaks in an underground LPG distribution system.

863 **Pipelines on Private Right-of-Way of Electric Transmission Lines.**

Where gas pipelines parallel overhead electric transmission lines on the same right of way, the company operating the pipelines shall take the following precautions:

863.1 Employ blow-out connections that will direct the gas away from the electric conductors.

863.2 Install a bonding conductor across points where the main is to be separated and maintain this connection while the pipeline is separated. The current carrying capacity of the bonding conductor should be at least one-half of the capacity of the overhead line conductors.

Note: (1) Refer to National Board of Fire Underwriters and the National Fire Protection Association Bulletins No. 58 — Storage and Handling of Liquified Petroleum Gases, and No. 59 — Liquified Petroleum Gases at Utility Gas Plants

863.3 Make a study in collaboration with the electric company on the common problems of corrosion and electrolysis, taking the following factors into consideration:

(a) The possibility of the pipeline carrying either unbalanced line currents or fault currents.

(b) The possibility of lightning or fault currents inducing voltages sufficient to puncture pipe coating or pipe.

(c) Cathodic protection of the pipeline, including location of ground beds, especially if the electric line is carried on steel towers.

(d) Desirability of installing electric bonding connections between the pipeline and either the steel tower footings or the buried ground facilities or the ground-wire of the overhead electric system.

863.4 Investigate the necessity of protecting insulating joints in the pipeline against induced voltages or currents resulting from lightning strokes. Such protection can be obtained by connecting buried sacrificial anodes to the pipe near the insulating joints or by bridging the pipeline insulator with a spark-gap or by other effective means.

API Specifications for Line Pipe

STANDARD-WEIGHT THREADED LINE PIPE DIMENSIONS, WEIGHTS, AND TEST PRESSURES

1	2	3	4	5	6	7	8	9	10	11	12
					Calculated Weight, lb. per ft.			Test Pressure, psi., min.			
								Steel			Iron
Size: Nominal, in.	Outside Diameter, in. D	Nominal Weight:[1] Threads and Coupling, lb. per ft.	Wall Thickness[2], in. t	Inside Diameter[2], in. d	Plain End w_{pe}	Threads and Coupling[1] w	Calculated Coupling Weight, lb.	Butt-Welded	Lap-Welded and Grade A	Grade B	Open-Hearth and Wrought[3]
⅛	0.405	0.25	0.068	0.269	0.24	0.25	0.04	700	700	700	700
¼	0.540	0.43	0.088	0.364	0.42	0.43	0.09	700	700	700	700
⅜	0.675	0.57	0.091	0.493	0.57	0.57	0.13	700	700	700	700
½	0.840	0.86	0.109	0.622	0.85	0.86	0.24	700	700	700	700
¾	1.050	1.14	0.113	0.824	1.13	1.14	0.34	700	700	700	700
1	1.315	1.70	0.133	1.049	1.68	1.69	0.54	700	700	700	700
1¼	1.660	2.30	0.140	1.380	2.27	2.30	1.03	800	1000	1100	800
1½	1.900	2.75	0.145	1.610	2.72	2.74	0.90	800	1000	1100	800
2	2.375	3.75	0.154	2.067	3.65	3.71	1.86	800	1000	1100	800
2½	2.875	5.90	0.203	2.469	5.79	5.88	3.27	800	1000	1100	800
3	3.500	7.70	0.216	3.068	7.58	7.67	4.09	800	1000	1100	800
3½	4.000	9.25	0.226	3.548	9.11	9.27	5.92	1200	1200	1300	950
4	4.500	11.00	0.237	4.026	10.79	11.01	7.59	1200	1200	1300	950
5	5.563	15.00	0.258	5.047	14.62	14.90	9.38	.....	1200	1300	950
6	6.625	19.45	0.280	6.065	18.97	19.33	12.92	.....	1200	1300	950
8	8.625	25.55	0.277	8.071	24.70	25.44	23.18	.....	1200	1300	950
* 8	**8.625**	**29.35**	**0.322**	7.981	**28.55**	29.25	23.18	.....	1300	1600	950
10	10.750	32.75	0.279	10.192	31.20	32.20	31.55	.....	1000	1200	800
10	10.750	35.75	0.307	10.136	34.24	35.20	31.55	.....	1000	1200	800
*10	**10.750**	**41.85**	**0.365**	10.020	**40.48**	41.35	31.55	.....	1200	1400	800
12	12.750	45.45	0.330	12.090	43.77	45.40	49.27	.....	1000	1200	800
*12	**12.750**	**51.15**	**0.375**	12.000	**49.56**	51.10	49.27	.....	1100	1200	800
14D	14.000	57.00	0.375	13.250	54.57	55.80	45.83	.....	950	1100	750
16D	16.000	65.30	0.375	15.250	62.58	64.08	55.83	.....	850	1000	700
18D	18.000	73.00	0.375	17.250	70.59	72.37	66.53	.....	750	900	600
20D	20.000	81.00	0.375	19.250	78.60	80.70	79.37	.....	700	800	550

[1]Nominal weights, threads and coupling (Col. 3), are shown for the purpose of identification in ordering. Calculated weights, threads and coupling (Col. 7), are based on 20-ft lengths. See Par. 38 for weights applying to longer or shorter lengths.

[2]The weight per cubic inch is slightly less for wrought iron than for steel. Since wrought-iron pipe is made with the same weight per foot as steel pipe, the wall thickness of wrought-iron pipe is 2 to 3 per cent greater than the tabulated values above, and the inside diameter is correspondingly smaller.

[3]Test pressures shown apply to seamless, electric-welded, and lap-welded open-hearth-iron pipe, and to lap-welded wrought-iron pipe. Pressures shown for sizes 3-in. nominal and smaller apply also to butt-welded open-hearth-iron pipe, and in sizes 2-in. nominal and smaller apply to butt-welded wrought-iron pipe.

*Dimensions and weights shown in bold face are the same as for ASA B 36.10 standard-wall pipe in this diameter.

NOTE: Lap-welded pipe is produced currently in 2⅜-in. through 16-in. outside diameters.

STANDARD-WEIGHT PLAIN-END LINE PIPE DIMENSIONS, WEIGHTS, AND TEST PRESSURES

1	2	3	4	5	6	7	8	9
					Test Pressure, psi., min.			
					Steel			Iron
Size: Nominal, in.	Outside Diameter, in. D	Plain-End Weight, lb. per ft.	Wall Thickness[1], in. t	Inside Diameter[1], in. d	Butt-Welded	Lap-Welded and Grade A	Grade B	Open-Hearth and Wrought[2]
⅛	0.405	0.24	0.068	0.269	700	700	700	700
¼	0.540	0.42	0.088	0.364	700	700	700	700
⅜	0.675	0.57	0.091	0.493	700	700	700	700
½	0.840	0.85	0.109	0.622	700	700	700	700
¾	1.050	1.13	0.113	0.824	700	700	700	700
1	1.315	1.68	0.133	1.049	700	7.00	700	700
1¼	1.660	2.27	0.140	1.380	1000	1200	1300	1000
1½	1.900	2.72	0.145	1.610	1000	1200	1300	1000
2	2.375	3.65	0.154	2.067	1000	1200	1300	1000
2½	2.875	5.79	0.203	2.469	1000	1200	1300	1000
3	3.500	7.58	0.216	3.068	1000	.....	.....	.....
3½	4.000	9.11	0.226	3.548	1200	.....	.....	.....
4	4.500	10.79	0.237	4.026	1200	.....	.....	.....

[1]The weight per cubic inch is slightly less for wrought iron than for steel. Since wrought-iron pipe is made with the same weight per foot as steel pipe, the wall thickness of wrought-iron pipe is 2 to 3 per cent greater than the tabulated values above, and the inside diameter is correspondingly smaller.

[2]Test pressures shown apply to seamless, electric-welded, and lap-welded open-hearth-iron pipe, and to lap-welded wrought-iron pipe. Test pressures apply also to butt-welded open-hearth-iron pipe. Test pressures for sizes 2-in. nominal and smaller apply also to butt-welded wrought-iron pipe.

NOTE: Lap-welded steel pipe conforming to Table 5 is produced currently only in the 2-in. and 2½-in. nominal sizes.

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REGULAR-WEIGHT PLAIN-END LINE PIPE DIMENSIONS, WEIGHTS, AND TEST PRESSURES

1	2	3	4	5	6	7
				Test Pressure, psi., min.		
				Steel		Iron
Size: Outside Diameter, in. D	Plain-End Weight, lb. per ft.	Wall Thickness[1], in. t	Inside Diameter[1], in. d	Lap-Welded and Grade A	Grade B	Open-Hearth and Wrought[2]
3½	6.63	0.188	3.124	1900	2200	1500
3½	7.58	0.216	3.068	2200	2500	1800
3½	8.68	0.250	3.000	2500	2500	2100
3½	9.67	0.281	2.938	2500	2500	2300
4½	8.64	0.188	4.124	1500	1800	1200
4½	10.00	0.219	4.062	1700	2000	1400
4½	10.79	0.237	4.026	1900	2200	1500
4½	11.35	0.250	4.000	2000	2300	1600
4½	12.67	0.281	3.938	2200	2500	1800
4½	13.98	0.312	3.876	2500	2500	2000
6⅝	12.80	0.188	6.249	1000	1200	800
6⅝	14.97	0.219	6.187	1200	1400	950
6⅝	17.02	0.250	6.125	1400	1600	1100
6⅝	18.97	0.280	6.065	1500	1800	1200
6⅝	21.07	0.312	6.001	1700	2000	1400
6⅝	23.06	0.344	5.937	1900	2200	1500
6⅝	25.03	0.375	5.875	2000	2400	1600
8⅝	16.90	0.188	8.249	800	900	650
8⅝	19.64	0.219	8.187	900	1100	750
8⅝	22.36	0.250	8.125	1000	1200	850
8⅝	24.70	0.277	8.071	1200	1300	950
8⅝	27.74	0.312	8.001	1300	1500	1000
8⅝	28.55	0.322	7.981	1300	1600	1000
8⅝	30.40	0.344	7.937	1400	1700	1100
8⅝	33.04	0.375	7.875	1600	1800	1300
8⅝	38.26	0.438	7.749	1800	2100	1500
10¾	24.60	0.219	10.312	750	850	600
10¾	28.04	0.250	10.250	850	1000	700
10¾	31.20	0.279	10.192	1000	1200	800
10¾	34.24	0.307	10.136	1000	1200	800
10¾	38.20	0.344	10.062	1100	1300	900
10¾	40.48	0.365	10.020	1200	1400	1000
10¾	48.19	0.438	9.874	1500	1700	1200
12¾	33.38	0.250	12.250	700	800	600
12¾	37.45	0.281	12.188	800	850	650
12¾	41.51	0.312	12.126	900	1000	700
12¾	43.77	0.330	12.090	1000	1200	800
12¾	45.55	0.344	12.062	1000	1200	800
12¾	49.56	0.375	12.000	1100	1200	850
12¾	57.53	0.438	11.874	1200	1400	1000
14	45.68	0.312	13.376	800	950	650
14	50.14	0.344	13.312	900	1000	700
14	54.57	0.375	13.250	950	1100	750
14	63.37	0.438	13.124	1100	1300	900
14	72.09	0.500	13.000	1300	1500	1000
16	52.36	0.312	15.376	700	800	550
16	57.48	0.344	15.312	750	900	600
16	62.58	0.375	15.250	850	1000	700
16	72.72	0.438	15.124	1000	1100	800
16	82.77	0.500	15.000	1100	1300	900
18	59.03	0.312	17.376	600	750	500
18	64.82	0.344	17.312	700	800	550
18	70.59	0.375	17.250	750	900	600
18	82.06	0.438	17.124	900	1000	700
18	93.45	0.500	17.000	1000	1200	800
20	65.71	0.312	19.376	550	650	450
20	72.16	0.344	19.312	600	700	500
20	78.60	0.375	19.250	700	800	550
20	91.41	0.438	19.124	800	900	650
20	104.13	0.500	19.000	900	1000	700

[1]The weight per cubic inch is slightly less for wrought iron than for steel. Since wrought-iron pipe is made with the same weight per foot as steel pipe, the wall thickness of wrought-iron pipe is 2 to 3 per cent greater than the tabulated values above, and the inside diameter is correspondingly smaller.

[2]Test pressures shown apply to seamless, electric-welded, and lap-welded open-hearth-iron pipe, and to lap-welded wrought-iron pipe.

NOTE: Lap-welded pipe is not produced currently in outside diameters larger than 16 in.

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WEIGHTS OF MECHANICAL JOINT PIPE FOR GAS

Standard thicknesses and weights of cast iron mechanical joint pipe centrifugally cast in metal and sand lined molds for gas

Note: Thicknesses in accordance with A.S.A. Specifications, 18,000 psi full length bursting tensile, 40,000 psi ring modulus of rupture. For pipe laid without blocks on flat bottom trench with tamped backfill under 5 feet of cover. For other conditions consult the manufacturer.

Size ins.	Thickness ins.	Outside Diam. ins.	Weight Based On 12 ft. Lgth.* Avg. per ft.	12 ft. Lgth.* per Lgth.	16 ft. Lgth.* Avg. per ft.	16 ft. Lgth.* per Lgth.	16½ ft. Lgth.* Avg. per ft.	16½ ft. Lgth.* per Lgth.	18 ft. Lgth.* Avg. per ft.	18 ft. Lgth.* per Lgth.	20 ft. Lgth.* Avg. per ft.	20 ft. Lgth.* per Lgth.
Class 10—10 Lb. Pressure												
4	.35(1)	4.80	16.6	200	16.4	260	16.3	270	16.2	290		
	or .38(2)	4.80	17.8	215	17.6	280	17.5	290	17.4	315		
6	.38(1)	6.90	26.1	315	25.7	410	25.6	420	25.5	460		
	or .41(2)	6.90	27.9	335	27.6	440	27.5	455	27.3	490		
8	.41	9.05	37.2	445	36.7	585	36.6	605	36.4	655		
10	.44	11.10	49.3	590	48.5	775	48.4	800	48.2	870		
12	.48	13.20	64.0	770	62.9	1005	62.8	1035	62.6	1125	62.3	1245
16	.50	17.40	90.7	1090	88.7	1420	88.6	1460	88.1	1585	87.6	1750
20	.57	21.60	128.7	1545	125.9	2015	125.7	2075	124.9	2250	124.2	2485
24	.63	25.80	170.2	2040	166.5	2665	166.1	2740	165.2	2975	164.2	3285
30	.73	32.00			241.5	3865	241.0	3975			238.0	4760
36	.81	38.30			322.4	5160						
42	.90	44.50			416.5	6665						
48	.98	50.80			519.0	8305						
Class 50—50 Lb. Pressure												
4	.35(1)	4.80	16.6	200	16.4	260	16.3	270	16.2	290		
	or .38(2)	4.80	17.8	215	17.6	280	17.5	290	17.4	315		
6	.38(1)	6.90	26.1	315	25.7	410	25.6	420	25.5	460		
	or .41(2)	6.90	27.9	335	27.6	440	27.5	455	27.3	490		
8	.41	9.05	37.2	445	36.7	585	36.6	605	36.4	655		
10	.44	11.10	49.3	590	48.5	775	48.4	800	48.2	870		
12	.48	13.20	64.0	770	62.9	1005	62.8	1035	62.6	1125	62.3	1245
16	.50	17.40	90.7	1090	88.7	1420	88.6	1460	88.1	1585	87.6	1750
20	.57	21.60	128.7	1545	125.9	2015	125.7	2075	124.9	2250	124.2	2485
24	.63	25.80	170.2	2040	166.5	2665	166.1	2740	165.2	2975	164.2	3285
30	.79	32.00			259.5	4150	259.0	4275			256.0	5120
36	.87	38.30			343.9	5500						
42	.97	44.50			445.7	7130						
48	1.06	50.80			557.1	8915						
Class 100—100 Lb. Pressure												
4	.35(1)	4.80	16.6	200	16.4	260	16.3	270	16.2	290		
	or .38(2)	4.80	17.8	215	17.6	280	17.5	290	17.4	315		
6	.38(1)	6.90	26.1	315	25.7	410	25.6	420	25.5	460		
	or .41(2)	6.90	27.9	335	27.6	440	27.5	455	27.3	490		
8	.41	9.05	37.2	445	36.7	585	36.6	605	36.4	655		
10	.44	11.10	49.3	590	48.5	775	48.4	800	48.2	870		
12	.48	13.20	64.0	770	62.9	1005	62.8	1035	62.6	1125	62.3	1245
16	.54	17.40	97.1	1165	95.0	1520	94.9	1565	94.5	1700	94.0	1880
20	.62	21.60	138.7	1665	135.9	2175	135.7	2240	134.9	2430	134.2	2685
24	.68	25.80	182.2	2185	178.5	2855	178.1	2940	177.2	3190	176.2	3525
Class 150—150 Lb. Pressure												
4	.35(1)	4.80	16.6	200	16.4	260	16.3	270	16.2	290		
	or .38(2)	4.80	17.8	215	17.6	280	17.5	290	17.4	315		
6	.38(1)	6.90	26.1	315	25.7	410	25.6	420	25.5	460		
	or .41(2)	6.90	27.9	335	27.6	440	27.5	455	27.3	490		
8	.41	9.05	37.2	445	36.7	585	36.6	605	36.4	655		
10	.44	11.10	49.3	590	48.5	775	48.4	800	48.2	870		
12	.48	13.20	64.0	770	62.9	1005	62.8	1035	62.6	1125	62.3	1245

* Including Bell. Calculated weight of pipe rounded off to nearest 5 pounds.
(1) Class 22 thickness.
(2) Class 23 thickness offers increased factor of safety and is recommended for use in areas of dense population and heavy traffic.
References: A.S.A.—A-21.7—pipe cast in metal molds. A.S.A.—A-21.9—pipe cast in sand lined molds. A.S.A.—A-21.11—mechanical joints.

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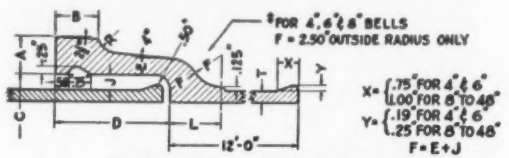
WEIGHTS OF MECHANICAL JOINT PIPE FOR GAS

Standard thicknesses and weights of cast iron mechanical joint pit cast pipe for gas

Note: Thicknesses in accordance with A.S.A. Specifications, 11,000 psi full length bursting tensile, 31,000 psi ring modulus of rupture. For pipe laid without blocks on flat bottom trench with tamped backfill under 5 feet of cover. For other conditions consult the manufacturer.

Size ins.	Outside Diam. ins.	Class 10 — 10 lb. Pressure — Weight Based on 12 ft. Lgth.* Thickness ins.	Avg. per ft.	per Lgth.	Class 50 — 50 lb. Pressure — Weight Based on 12 ft. Lgth.* Thickness ins.	Avg. per ft.	per Lgth.	Class 100 — 100 lb. Pressure — Weight Based on 12 ft. Lgth.* Thickness ins.	Avg. per ft.	per Lgth.	Class 150 — 150 lb. Pressure — Weight Based on 12 ft. Lgth.* Thickness ins.	Avg. per ft.	per Lgth.
4	4.80	.40	18.6	225	.40	18.6	225	.40	18.6	225	.40	18.6	225
6	6.90	.43	29.2	350	.43	29.2	350	.43	29.2	350	.43	29.2	350
8	9.05	.46	41.3	495	.46	41.3	495	.46	41.3	495	.46	41.3	495
10	11.10	.50	55.4	665	.50	55.4	665	.50	55.4	665	.50	55.4	665
12	13.20	.54	71.2	855	.54	71.2	855	.54	71.2	855	.54	71.2	855
16	17.40	.58	103.7	1245	.58	103.7	1245	.58	103.7	1245			
20	21.60	.66	147.2	1765	.66	147.2	1765	.71	157.1	1885			
24	25.80	.74	197.2	2365	.74	197.2	2365	.80	211.4	2535			
30	32.00	.87	291.8	3500	.87	291.8	3500						
36	38.30	.97	392.0	4705	.97	392.0	4705						
42	44.50	1.07	503.0	6035	1.07	503.0	6035						
48	50.80	1.18	634.3	7610	1.18	634.3	7610						

* Including Bell. Calculated weight of pipe rounded off to nearest 5 pounds.
References: Thicknesses—A.S.A.—A-21.3—pit cast for gas Mechanical joint—A.S.A.—A-21.11.



BELL NO. 1—STANDARD BELL

Nom. Diam. Ins.	Actual Outside Diam. Ins.	T	Actual Inside Diam. Ins.	Dimensions in Inches A	B	C	D	E	F	J	L	R	Approximate Weight in Pounds Bell †	Per ft. *	12' 0" Lgth.
4	4.80	.40	4.00	1.30	1.50	5.80	4.00	.59	1.09	.50	3.25	.75	27.0	19.50	234
6	6.90	.43	6.04	1.40	1.50	7.90	4.00	.62	1.12	.50	3.25	.80	39.5	30.58	367
8	9.05	.45	8.15	1.50	1.50	10.05	4.00	.69	1.19	.50	3.25	.80	52.8	42.42	509
10	11.10	.49	10.12	1.50	1.50	12.10	4.00	.69	1.19	.50	2.10	.90	57.93	55.91	671
12	13.20	.54	12.12	1.60	1.50	14.20	4.50	.75	1.25	.50	2.20	1.00	79.47	73.83	886
16	17.40	.62	16.16	1.80	1.75	18.40	4.50	.90	1.40	.50	2.50	1.10	125.18	113.58	1351
20	21.60	.68	20.24	2.00	1.75	22.85	4.50	.97	1.60	.63	2.80	1.15	169.10	153.83	1846
24	25.80	.76	24.28	2.10	2.00	27.05	5.00	1.05	1.68	.63	2.80	1.25	235.10	206.41	2477
30	31.74	.85	30.04	2.30	2.00	32.99	5.00	1.15	1.78	.63	3.00	1.30	315.20	284.00	3408
36	37.96	.95	36.06	2.50	2.00	39.21	5.00	1.25	1.88	.63	3.20	1.40	410.20	379.25	4551
42	44.20	1.07	42.06	2.80	2.00	45.45	5.00	1.40	2.03	.63	3.40	1.45	537.50	497.66	5972
48	50.50	1.26	47.98	3.00	2.00	51.75	5.00	1.50	2.13	.63	3.60	1.60	657.00	663.50	7962

Note—Pipe heavier than these standards may be made by reducing the cores, or internal diameters "C" and "D"; same for specials.

Dimension "L" for sizes 4", 6" and 8", and Dimension "F", shown in sketch as 2.50 (outside radius only), apply to bells of *straight pipe only*. For bells of *special castings* the correct dimensions for "F" and "L" are.

Size	"F"	"L"
4	1.09	1.90
6	1.12	2.00
8	1.19	2.10

*Weight per foot includes Bell and Bead.
†Weight of Bell includes only metal beyond O. D. of pipe.
‡See Sketch for Special outside radius dimensions for 4", 6" and 8" Bells.

STANDARD THICKNESSES OF CAST IRON PIT CAST PIPE FOR GAS

THICKNESS IN INCHES. WORKING PRESSURE IN POUNDS PER SQUARE INCH.
THICKNESSES INCLUDE ALLOWANCES FOR FOUNDRY PRACTICE AND CORROSION
Laying Condition A — Flat Bottom Trench, Without Blocks, Untamped Backfill
Laying Condition B — Flat Bottom Trench, Without Blocks, Tamped Backfill
Laying Condition C — Pipe Laid on Blocks, Untamped Backfill
Laying Condition D — Pipe Laid on Blocks, Tamped Backfill

Size Inches	Working Pressure	3½ FEET OF COVER				5 FEET OF COVER				8 FEET OF COVER			
		Laying Condition				Laying Condition				Laying Condition			
		A	B	C	D	A	B	C	D	A	B	C	D
4	10	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40	.46	.40
	50	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40	.50	.40
	100	.40	.40	.40	.40	.40	.40	.43	.40	.40	.40	.50	.40
	150	.40	.40	.40	.40	.40	.40	.43	.40	.40	.40	.50	.40
6	10	.43	.43	.46	.43	.43	.43	.50	.43	.43	.43	.54	.43
	50	.43	.43	.46	.43	.43	.43	.50	.43	.43	.43	.54	.43
	100	.43	.43	.46	.43	.43	.43	.50	.43	.43	.43	.58	.43
	150	.43	.43	.50	.43	.43	.43	.50	.43	.43	.43	.58	.43
8	10	.46	.46	.50	.46	.46	.46	.54	.46	.46	.46	.58	.46
	50	.46	.46	.54	.46	.46	.46	.54	.46	.46	.46	.63	.46
	100	.46	.46	.54	.46	.46	.46	.58	.46	.46	.46	.63	.46
	150	.46	.46	.54	.46	.46	.46	.58	.46	.46	.46	.63	.46
10	10	.50	.50	.54	.50	.50	.50	.58	.50	.50	.50	.68	.50
	50	.50	.50	.58	.50	.50	.50	.58	.50	.50	.50	.68	.54
	100	.50	.50	.58	.50	.50	.50	.63	.50	.54	.50	.68	.54
	150	.50	.50	.58	.50	.50	.50	.63	.50	.54	.50	.68	.58
12	10	.54	.54	.58	.54	.54	.54	.63	.54	.54	.54	.68	.58
	50	.54	.54	.58	.54	.54	.54	.63	.54	.58	.54	.73	.58
	100	.54	.54	.63	.54	.54	.54	.63	.54	.58	.58	.73	.58
	150	.54	.54	.63	.58	.58	.54	.68	.58	.63	.58	.79	.63
16	10	.58	.58	.68	.58	.58	.58	.68	.63	.68	.63	.79	.68
	50	.58	.58	.68	.63	.63	.58	.73	.63	.68	.63	.79	.73
	100	.63	.58	.73	.63	.63	.58	.73	.68	.73	.68	.85	.73
20	10	.66	.66	.77	.71	.71	.66	.83	.71	.77	.71	.90	.83
	50	.71	.66	.77	.71	.71	.66	.83	.77	.77	.71	.90	.83
	100	.71	.66	.83	.77	.77	.71	.83	.77	.83	.77	.97	.83
24	10	.74	.74	.80	.74	.80	.74	.86	.80	.86	.80	.93	.86
	50	.80	.74	.86	.80	.80	.74	.93	.86	.86	.80	1.00	.93
	100	.80	.74	.93	.86	.86	.80	.93	.86	.93	.86	1.00	.93
30	10	.87	.87	.94	.87	.94	.87	1.02	.94	1.02	.87	1.10	1.02
	50	.94	.87	1.02	.94	.94	.87	1.10	1.02	1.10	.94	1.19	1.10
36	10	1.05	.97	1.05	.97	1.05	.97	1.13	1.05	1.13	.97	1.22	1.13
	50	1.05	.97	1.13	1.05	1.13	.97	1.22	1.13	1.22	1.05	1.32	1.22
42	10	1.16	1.07	1.16	1.07	1.16	1.07	1.25	1.16	1.35	1.07	1.35	1.25
	50	1.16	1.07	1.25	1.16	1.25	1.07	1.35	1.25	1.35	1.16	1.46	1.35
48	10	1.27	1.18	1.37	1.18	1.37	1.18	1.37	1.27	1.48	1.18	1.60	1.37
	50	1.27	1.18	1.37	1.27	1.37	1.18	1.48	1.37	1.48	1.27	1.60	1.48

NOTE: This table is taken from ASA A21.3

STANDARD THICKNESS OF CAST IRON GAS PIPE CENTRIFUGALLY CAST IN METAL MOLDS OR SAND LINED MOLDS

THICKNESS IN INCHES. WORKING PRESSURE IN POUNDS PER SQUARE INCH
THICKNESSES INCLUDE ALLOWANCES FOR FOUNDRY PRACTICE AND CORROSION
Laying Condition A — Flat Bottom Trench, Without Blocks, Untamped Backfill
Laying Condition B — Flat Bottom Trench, Without Blocks, Tamped Backfill
Laying Condition C — Pipe Laid on Blocks, Untamped Backfill
Laying Condition D — Pipe Laid on Blocks, Tamped Backfill

Size Inches	Working Pressure	3½ FEET OF COVER				5 FEET OF COVER				8 FEET OF COVER			
		Laying Condition				Laying Condition				Laying Condition			
		A	B	C	D	A	B	C	D	A	B	C	D
4	10	.35[1]	.35	.35	.35	.35	.35	.35	.35	.35	.35	.41	.35
		.38[2]	.38	.38	.38	.38	.38	.38	.38	.38	.38	.41	.38
	50	.35[1]	.35	.35	.35	.35	.35	.35	.35	.35	.35	.41	.35
		.38[2]	.38	.38	.38	.38	.38	.38	.38	.38	.38	.41	.38
	100	.35[1]	.35	.35	.35	.35	.35	.35	.35	.35	.35	.41	.35
		.38[2]	.38	.38	.38	.38	.38	.38	.38	.38	.38	.41	.38
	150	.35[1]	.35	.35	.35	.35	.35	.38	.35	.35	.35	.41	.35
		.38[2]	.39	.38	.38	.38	.38	.38	.38	.38	.38	.41	.38
6	10	.38[1]	.39	.41	.38	.38	.38	.41	.38	.38	.38	.48	.38
		.41[2]	.41	.41	.41	.41	.41	.41	.41	.41	.41	.48	.41
	50	.39[1]	.38	.41	.38	.38	.38	.41	.38	.38	.38	.49	.38
		.41[2]	.41	.41	.41	.41	.41	.41	.41	.41	.41	.48	.41
	100	.38[1]	.38	.41	.38	.38	.38	.44	.38	.38	.38	.48	.38
		.41[2]	.41	.41	.41	.41	.41	.44	.41	.41	.41	.48	.41
	150	.39[1]	.38	.41	.38	.38	.38	.44	.38	.38	.38	.48	.38
		.41[2]	.41	.41	.41	.41	.41	.44	.41	.41	.41	.48	.41
8	10	.41	.41	.44	.41	.41	.41	.48	.41	.41	.41	.52	.41
	50	.41	.41	.44	.41	.41	.41	.48	.41	.41	.41	.52	.41
	100	.41	.41	.49	.41	.41	.41	.48	.41	.41	.41	.56	.41
	150	.41	.41	.48	.41	.41	.41	.48	.41	.41	.41	.56	.41
10	10	.44	.44	.48	.44	.44	.44	.52	.44	.44	.44	.60	.44
	50	.44	.44	.48	.44	.44	.44	.52	.44	.44	.44	.60	.44
	100	.44	.44	.52	.44	.44	.44	.52	.44	.44	.44	.60	.48
	150	.44	.44	.52	.44	.44	.44	.56	.44	.48	.44	.60	.48
12	10	.48	.48	.52	.48	.48	.48	.56	.48	.48	.48	.60	.52
	50	.48	.48	.52	.48	.48	.48	.56	.48	.48	.48	.60	.52
	100	.48	.48	.56	.48	.48	.48	.56	.48	.52	.48	.65	.52
	150	.48	.48	.56	.48	.48	.48	.56	.48	.52	.48	.65	.52
16	10	.54	.50	.58	.54	.54	.50	.63	.58	.58	.54	.73	.63
	50	.54	.50	.63	.54	.54	.50	.63	.58	.63	.58	.73	.63
	100	.54	.54	.63	.58	.58	.54	.68	.58	.63	.58	.73	.68
20	10	.62	.57	.67	.62	.62	.57	.72	.67	.67	.62	.78	.72
	50	.62	.57	.72	.62	.67	.57	.72	.67	.72	.62	.78	.72
	100	.62	.57	.72	.67	.67	.62	.78	.67	.72	.67	.84	.78
24	10	.68	.64	.73	.68	.73	.63	.79	.73	.79	.68	.85	.79
	50	.68	.63	.79	.68	.73	.63	.79	.73	.79	.73	.85	.79
	100	.73	.63	.79	.73	.73	.68	.85	.79	.79	.73	.92	.85
30	10	.79	.73	.85	.79	.85	.73	.92	.85	.92	.79	.99	.92
	50	.85	.73	.85	.85	.85	.79	.92	.85	.92	.85	.99	.92
36	10	.87	.81	.94	.87	.94	.81	1.02	.94	1.02	.87	1.10	1.02
	50	.94	.81	1.02	.94	1.02	87	1.10	.94	1.10	.94	1.19	1.02
42	10	1.05	.90	1.05	.97	1.05	.90	1.13	1.05	1.13	.97	1.22	1.13
	50	1.05	.90	1.13	1.05	1.13	.97	1.13	1.05	1.22	1.05	1.32	1.13
48	10	1.14	.98	1.14	1.06	1.14	.98	1.23	1.14	1.33	1.06	1.33	1.23
	50	1.14	.98	1.23	1.14	1.23	1.06	1.33	1.14	1.33	1.14	1.44	1.33

[1]Class 22 Thickness.
[2]Class 23 Thickness offers increased factor of safety and is recommended for use in areas of dense population and heavy traffic.

NOTE: This table is taken from ASA A21.7 and A21.9

Gas Flow Formulas

HIGH PRESSURE GAS FLOW

Weymouth Formula

The Weymouth formula, considered to be the one best known and most widely used, is as follows:

$$Q = 433.5\frac{T_o}{P_o}\frac{d^{8/3}}{\sqrt{GTL}}[P_1^2(1 + \tfrac{2}{3}JP_1) - P_2^2(1 + \tfrac{2}{3}JP_2)_{Z/I}[$$

Where:

- Q = flow, cubic feet per day under standard conditions P_o and T_o
- P_o = standard pressure of measurement (psia)
- T_o = standard temperature of measurement, F
- T = absolute temperature of flowing gas, F
- P_1 = initial pressure, psia
- P_2 = terminal pressure, psia
- d = internal diameter of pipe, inches
- L = length of line, miles
- G = specific gravity of gas, (air = 1.0)
- J = factor defined by relationship: $Z(1 + JP) = 1$
- Z = supercompressibility factor

The general formula may be simplified for preliminary pipe line design purposes and general office use by combining the factors representing the properties of a typical United States gas with the standards of pressure and temperature and flowing temperature usually encountered in practice, to form a single Constant.

Thus, by adopting as typical, the natural gas No. 1 of Table 2 of the article on "Deviation of Gases from Ideal Gas Laws," (page 26), having a specific gravity of 0.627, a heating value of 1063, critical pressure of 672.0 psia and critical temperature of 363.7F absolute; and assuming P_o at 14.73 psia, T_o at $60 + 460 = 520$F absolute, and T at $50 + 460 = 510$F absolute;

$$Q = K\frac{d^{8/3}}{\sqrt{L}}[P_1^2(1 + \tfrac{2}{3}JP_1) - P_2^2(1 + \tfrac{2}{3}JP_2)]^{1/2}$$

in which $K = 433.5\frac{T_o}{P_o\sqrt{GT}} = 862.5$ for the conditions assumed above.

For this gas and at operating line pressures ranging from 500 to 1200 pounds absolute, the value of J may be assumed to average 0.0002 per 1 psia.

For conditions other than those assumed above, K can be corrected by multiplying by such of the following factors as may be appropriate:

$$\frac{T_o}{520};\quad \frac{14.73}{P_o};\quad \sqrt{\frac{0.627}{G}};\quad \sqrt{\frac{510}{T}}.$$

Formula for Determining Mean Pressure (P_m) in Pipe Line

$$P_m = \frac{2}{3}\left[P_1 + P_2 - \frac{P_1P_2}{P_1 + P_2}\right]$$

Loop Line Equivalents: A line composed of several lengths L_1, L_2, etc., of diameter d_1, d_2, etc., in series, can be transformed into a single equivalent line of uniform diameter d_o, by determining the equivalent length of each individual section by means of formula

$$L_{o,1} = L\left(\frac{d_o}{d_1}\right)^{16/3}$$

and adding these equivalent section lengths together to form an equivalent line of diameter d and total length L.

To transform a length of pipe of diameter d and length L to a pipe of equivalent capacity having a length L, the diameter of the equivalent section will be

$$d_o = d\left(\frac{L_o}{L}\right)^{3/16}$$

The diameter of a single pipe having a capacity equivalent to the aggregate capacity of several parallel, or looped lines of a common length and of diameters d_1, d_2, etc., is equal to

$$d_o = [d_1^{8/3} + d_2^{8/3} + \text{etc.}\ldots.]^{3/8} = [\Sigma\, d^{8/3}]^{3/8}$$

If the several loops have different lengths, the actual diameters of the loops must first be transformed into equivalent diameters of pipe having a common length and these equivalent diameters then be added in accordance with the formula just given.

The Panhandle Formula*

The original Panhandle Flow Formula has been used by many companies for calculating flow in large diameter (12-in. or larger) lines. This basic formula is:

$$Q = 435.87e\left(\frac{T_o}{P_o}\right)^{1.07881}\left(\frac{(P_1^2 - P_2^2)}{G^{0.8539}T_fL}\right)^{0.5394}d^{2.6182}$$

Substituting:

- T_o = Base temperature = $60° + 460° = 520°$ abs
- P_o = Base pressure = 14.73 psia
- T_f = Flowing temperature = $50° + 460° = 510°$ abs
- G = Gravity of gas = 0.686 (Panhandle gas)

and where:

- P_1 = Initial pressure — psia
- P_2 = Final pressure — psia
- L = Length of line in miles
- d = Diameter of pipe in inches
- e = Experience factor

the equation can be resolved to:

$$Q/d^{2.6182} = 839.51e\left(\frac{(P_1^2 - P_2^2)}{L}\right)^{0.5394}$$

Recently, this formula was revised, and the revision is known as the "Modified Panhandle Flow Formula." The complete formula accounts for differences in elevation and compressibility. For calculations requiring only a fair amount of accuracy, these two factors can be omitted. The simplified version of the modified formula is:

$$Q = 737\left(\frac{T_o}{P_o}\right)^{1.02}E\left(\frac{P_1^2 - P_2^2}{\bar{r}_f L G^{.961}}\right)^{0.510} \times D^{2.53}$$

Where:

- Q = cubic feet per day at P_o and T_o,
- T_o = base temperature, F abs,
- P_o = base pressure, psia,

*Complete details on how the modified formula was derived were given in the May and June, 1956, issue of *The Petroleum Engineer*, along with a graphical method of solution.

E = efficiency factor,
P_1 = upstream pressure, psia,
P_2 = downstream pressure, psia,
T_f = flowing temperature, F abs.
L = length of pipe line, miles
G = gas gravity referred to air,
D = inside diameter of pipe, in.

LOW PRESSURE GAS FLOW

The Spitzglass Formulas

For distribution system problems the Spitzglass formulas are most commonly used. These formulas are:

FOR PRESSURES NOT EXCEEDING ONE POUND GAGE:

$$Q = 3550\,K\left(\frac{h}{S\,L}\right)^{1/2}$$

Where:

Q = Flow per hour in cu ft at 14.73 psia and 60F.
H = Pressure drop in inches of water column.
S = Specific gravity of gas. (Air = 1.0).
L = Length of pipe in feet.
d = Internal diameter of pipe in inches.

$$K = \left(\frac{d^5}{1 + \frac{3.6}{d} + 0.03d}\right)^{1/2}$$

FOR PRESSURES EXCEEDING ONE POUND GAGE:

$$Q = 4830\,K\left(\frac{Pa}{sL}\right)^{1/2}$$

Where:

Q = Flow per hour in cu ft at 14.73 psia and 60F.
P = Pressure drop between pipe terminals in psi.
a = Average pressure in pipe line, psia. (Absolute initial pressure minus half the pressure drop.)
S = Specific gravity of gas. (Air = 1.0).
L = Length of pipe in feet.
d = Internal Diameter of pipe in inches.

$$K = \left(\frac{d^5}{1 + \frac{3.6}{d} + 0.03d}\right)^{1/2}$$

Values of $d^{5/3}$

Diameter in Inches External	Internal (d)	$d^{5/3}$
2.375	2.067	6.93
2.500	3.068	19.87
4.500	4.026	41.02
6.625	6.065	122.4
8.625	7.981	254.3
10.75	10.02	466.8
12.75	12.00	755.0
14.00	13.25	983.5
16.00	15.25	1,430.2
18.00	17.25	1,986.6
20.00	19.25	2,661.6
22.00	21.25	3,465.0
24.00	23.125	4,340.8
26.00	25.125	5,415.0
28.00	27.125	6,642.3
30.00	29.125	8,030.0

The Fritzsche Formula

This variable density formula is recommended by some companies for computing systems having operating pressures of 15 psig or less, and more specifically, for the 2 to 15 psig range in small diameter pipe (8-in. or smaller). The formula is:

$$Q = \frac{1.72}{S^{0.462}}\,\frac{T_o}{P_o}\left[\frac{(P_1^2 - P_2^2)\,d^5}{10^3\,T_1\,L}\right]^{0.538}$$

and

$$Z = P_1^2 - P_2^2 = \frac{S^{0.86}}{2.72}\left(\frac{P_o}{T_o}\right)^{1.85}\left(\frac{T_1\,10^3\,L}{d^5}\right)Q^{1.85}$$

($Z = (P_1^2 - P_2^2)$ or $(fP_1 - fP_2)$ in studies of compressible gases)

$$Z = \left(\frac{2.614\,S^{0.86}}{10^4}\right)\left(\frac{10^6\,L}{d^5}\right)Q^{1.85}$$

Where:

Q = flow in cubic feet per hour at 14.73 psi and 60F
$T_o = T_1 = 520$ R
P_o = 14.73 psi
S = 0.65 sp gr

The Pole Formula

Another formula that has been used in computing low pressure services is the Pole formula, expressed as follows:

$$Q = 876\sqrt{\frac{d^5\,h}{g\,l}}$$

Where:

Q = Flow per hour in cubic feet at 60F
d = inside diameter, inches
h = pressure drop
g = specific gravity of gas (air = 1.0)
l = length of main in ft

Values of $\sqrt{5^5}$

Diameter (d) inches (internal)	$\sqrt{d^5}$
.75	.4871
.824 (¾" pipe)	.6163
1.000	1.000
1.049 (1" pipe)	1.127
1.38 (1¼" pipe)	2.237
1.50	2.756
1.61 (1½" pipe)	3.289
2.00	5.657
2.067 (2" pipe)	6.143
2.479 (2½" pipe)	9.579
3.00	15.59
3.068	16.49
4.00	32.00
4.026	32.52
6.00	88.18
8.00	181.0
10.00	316.2
12.00	498.8
16.00	1024.
20.00	1789.
24.00	2822.
30.00	4930.
36.00	7776.

FACTORS TO APPLY TO LOW PRESSURE FORMULAS (1-LB AND UNDER) UNDER VARYING CONDITIONS TO OBTAIN GAS DELIVERY QUANTITIES

When the main is fed from one end and discharged at the other:

Assuming that the pressure drop h and the specific gravity S remain constant, then the only variable in the Spitzglass formula

$$Q = 3550\ K \sqrt{\frac{h}{SL}}$$

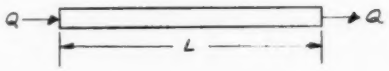
Example A

is the length L

$$\therefore\ 3550\ K \sqrt{\frac{h}{s}} = \text{constant} = C$$

$$\text{then } Q = C \sqrt{\frac{1}{L}}$$

total flow when main is fed from one end and discharged at the other.



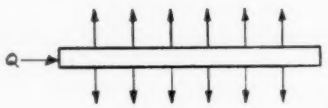
When the main is fed from one end and discharged at intervals along the main line:

This factor was obtained from the Gas Engineers' Handbook.* Assuming equal intervals between services, equal demands per service, and a total of 40 services on the line. This factor is correct within 1.0 per cent from 20 to 10,000 services on the line.

Example B

$$\text{then } Q = 1.7\ C \sqrt{\frac{1}{L}}$$

total flow when main is fed from one end and discharged at intervals along the line.



(*Published by McGraw-Hill Book Company, New York, New York, 1934.)

When the main is fed from both ends and discharged at intervals along the line:

Assume that ½ of the total flow is being fed through each end, then the point of no flow would be at ½ of the total length.

From EXAMPLE B,

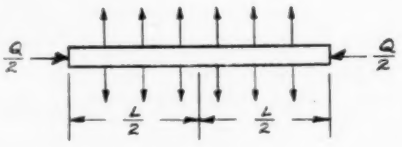
Example C

$$\frac{Q}{2} = 1.7\ C \sqrt{\frac{\frac{1}{L}}{2}} = 1.7\ C \sqrt{\frac{2}{L}}$$

$$Q = 2 \times 1.7 \sqrt{2}\ C \sqrt{\frac{1}{L}}$$

$$Q = 4.8\ C \sqrt{\frac{1}{L}}$$

total flow when main is fed from both ends and discharged at intervals along the line.



When the main is fed from both ends and the middle and discharged along the line:

Assume that the flow fed at the middle is double that fed at each end, the point of no flow would be ¼ the total length from EXAMPLE B,

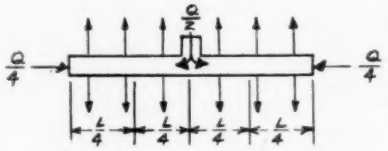
Example D

$$\frac{Q}{4} = 1.7\ C \sqrt{\frac{\frac{1}{L}}{4}} = 1.7\ C \sqrt{\frac{4}{L}}$$

$$Q = 4 \times 2 \times 1.7\ C \sqrt{\frac{1}{L}}$$

$$Q = 13.6\ C \sqrt{\frac{1}{L}}$$

total flow when main is fed from both ends and the middle and discharged at intervals along the line.



Gas Service Design

For Residential and Small Commercial Services

This section is adapted from a report given by members of the AGA Gas Service Design task force at the 1956 AGA Distribution Conference. The methods and practices noted herein are based on practices and methods used by companies replying to the task force's questionnaire, which served as a basis for the original report. The design practices and methods suggested in this section on Gas Service Design are for the guidance of the reader and user, who should adapt these recommendations to his own problems only after comparing them to his own experiences. Further useful information may be found in the sections of this handbook on the ASA Code and on Low Pressure Gas Flow Formulas and service design.

—The Editors.

Pressure Ranges

Although gas is distributed at many different pressure ranges, most of the companies consider as low pressure any pressure less than ½ psig. For the purposes of this report, intermediate pressure is taken as from 1 to 15 psig and high pressure from 15 to 60 psig. A maximum pressure of less than 50 psig is preferred by most companies while the maximum pressure allowed within the house is limited to 25 psig by more than 50 per cent of the companies.

ESTIMATED DEMAND OF GAS APPLIANCES 1000 BTU/CF	CFH
DOMESTIC GAS RANGE	60
STORAGE WATER HEATER - TO 30 GAL.	30
GAS REFRIGERATOR	4
CLOTHES DRYER	18
SPACE HEATING: HOT AIR (PER ROOM)	20
SPACE HEATING: STEAM OR HOT WATER (PER ROOM)	30
LOAD FACTORS: DOMESTIC PLUS SPACE HEATING - USE 90% OF TOTAL SPACE HEATING ONLY - USE 100%	

FIG. 1. Estimated demand of gas appliances.

Pipe Sizing

The most important problem initially in the design of a gas service is the selection of the pipe size. Many different bases are available and used in selecting the proper size. Some use a maximum size for all services; others make a detailed pressure drop calculation for each installation. Here is a brief description of the methods followed by a majority of the companies:

Consideration of connected load, length of service, and main pressure are made in selecting service pipe size. Generally this combination of variables is handled by means of selecting an allowable pressure drop for a particular main pressure and then selecting the pipe size based upon length of service and anticipated load, which will result in a calculated pressure drop of less than the allowable.

As it is usually the easiest to determine the connected load on a gas service, this flow is used to size the service pipe. Some companies refine the principle by introducing a diversity factor based upon the assumption that all of the appliances will not be in use at the same time. Others assume that the service will ultimately supply a piece of gas space heating equipment and size the service for this load even if no house heating load is installed at present.

The pressure drop allowed on a gas service is primarily a function of the pressure being carried on the mains during the time the mains are supplying the peak demand.

In a low pressure system, operating at a nominal main pressure of from 6 to 8 in. of water column, most companies consider the maximum allowable pressure drop on a gas service to be either 0.3-in. or 0.5-in. of water column.

An intermediate pressure system

FLOW CAPACITY - CFH - SP G 0.70						
LENGTH IN FEET	STANDARD STRAIGHT STEEL PIPE					
	0.3" H_2O DROP		7.0" H_2O DROP		1/2 lb. DROP	
	1"	1 1/4"	1"	1 1/4"	3/4"	1"
10	270	490	1270	2390	880	1900
20	240	440	1130	2100	790	1650
30	210	385	1010	1850	700	1420
40	180	332	885	1600	610	1225
50	162	295	785	1440	540	1100
60		270	710	1300	490	1010
70		250	660	1200	460	935
80		234	615	1130	430	880
90		220	580	1070	405	825
100		210	555	1000	385	780
120		190	505	925	348	710
140			470	860	322	660
160			440	800	300	615
180			415	750	285	580
200			390	715	270	550
250			350	639	240	493
300			320	580	220	448

FIG. 2. Steel pipe capacity.

1/2" W.C. PRESSURE DROP
SPECIFIC GRAVITY 0.65

EQUIVALENT FOOTAGE INCLUDED			
SIZE SERVICE	1 1/4"	1 1/2"	2"
TAP OPENING	2	2.5	3
STREET TEE	7.5	9	12
STREET ELL	4	5	6
STOP COCK	3	3.5	4
TOTAL	16.5	20.0	25.0

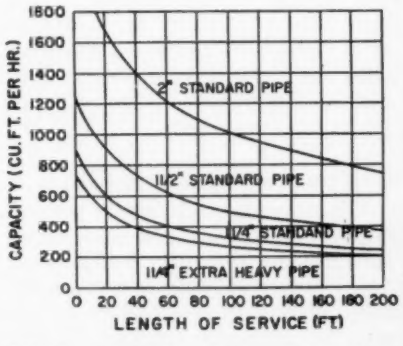


FIG. 3. Guide for sizing service pipe.

FLOW CAPACITY-CFH-TYPE "L" COPPER TUBING-SPG. 0.70												
LENGTH IN FEET	0.3" H_2O DROP		0.5" H_2O DROP		7.0" H_2O DROP			1/2 lb. DROP			1 lb. DROP	
	1"	1 1/4"	1"	1 1/4"	3/4"	1"	1 1/4"	3/4"	1"	1 1/4"	1/2"	3/4"
10	290	530	384	685	730	1400	2550	1025	1980	3600	380	1460
20	250	455	332	590	630	1210	2200	900	1750	3100	325	1250
30	220	395	287	520	550	1070	1900	770	1500	2700	285	1100
40	190	345	252	450	475	930	1650	675	1310	2325	248	950
50	170	308	223	400	430	830	1480	600	1160	2080	220	865
60		280	205	367	395	760	1350	545	1060	1900	200	780
70		260	190	340	360	700	1250	510	980	1750	185	725
80		244	178	319	340	660	1160	475	925	1640	173	675
90		230		298	320	620	1100	447	870	1550		640
100		219		282	300	590	1050	422	815	1475		610

FIG. 4. Copper tubing capacity.

operating at a mains pressure of from 1 to 15 psig will generally permit an allowable pressure drop of about ½ psig.

High pressure distribution systems permit allowable pressure drops of from ½ to 3 psig. Another method of selecting the allowable pressure drop is to specify that it be some percentage of the main pressure during the maximum hour. This varies from 10 to 20 per cent.

These various methods are basically to be used in sizing services which will supply large loads. Construction practices, availability of materials, and reduced inventory lead many companies to specify certain pipe sizes for services. In low pressure systems 1¼-in. pipe is generally preferred by most, although 1½-in. pipe is specified by about one-third.

In intermediate and high pressure systems the favorite minimum pipe size is ¾-in. with some 1-in. pipe specified for use in intermediate pressure systems. These "standard" sizes have been selected by the companies using them because they will provide adequate capacity to meet the more detailed requirements outlined in the preceeding paragraphs.

Construction Specifications

Having selected a pipe size, the next problem is to design the construction specifications so that the service, when finally built, will conform to the established practice of the industry, comply with the applicable rules and regulations under which the company operates, and will be the safest and most economical service possible.

Several state regulatory commissions have recently enacted codes which govern in broad principles the design and construction of gas services. The gas industry, itself recognizing the need for a code or method of the practice common to all parts of the country, has cooperated and assisted in the revision and expansion of Section 8 of the American Standards Associations Code for Pressure Piping.

Here are some sample requirements extracted from various state codes:

Curb cocks must be installed on all services where a regulator is installed on customer's premises, and on all low pressure services where large groups of people gather. These curb cocks must be inspected annually. *(New York Code).*

House regulators and vents must be inspected and tested periodically to see that they are operating properly and vented safely. *(New York).*

Tamper-proof service cocks are to be installed on all services requiring a house regulator and should be inspected periodically. *(New York).*

House regulators operating at pressures greater than 10 psig shall be equipped with relief and breather vents terminating outside. *(Wisconsin).*

Relief vents shall be of sufficient size to relieve the whole capacity of the relief valve. *(Wisconsin).*

All underground piping not in use or planned for use should be disconnected by valve or other means. *(Wiscousin.)*

Service pipe shall not be laid in the same trench with other utilities, and where possible, should be laid at a higher level than other utilities. *(Public Housing Authority, Bull. LR-17, V).*

Service trench should be vented to minimize gas seepage. *(PHA Bulletin).*

Service entrances should be made above the floor line where there is a slab floor or unused or concealed crawl space. *(PHA Bulletin).*

Service pipe should be protected against loosening of pipe joints or pipe breakage by means of swing joints or other positive methods. *(PHA Bulletin).*

The Factory Mutual Engineering Division, Associated Factory Mutual Fire Insurance Companies, Loss Prevention Bulletin No. 11.88, makes some recommendations concerning gas service entrances. In general it recommends an above grade entrance; and where a below grade entrance is required it recommends that the pipe should be encased.

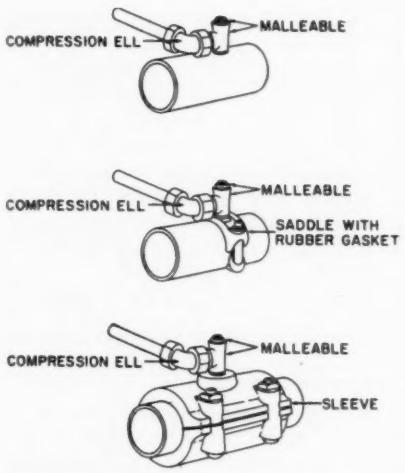


FIG. 5. Typical cast iron main connections.

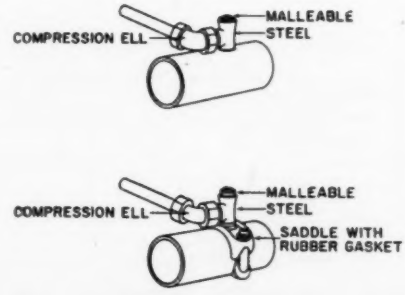


FIG. 6. Typical steel main connections.

ASA Piping Code

Section 8 of the American Standard Code for Pressure Piping (ASA B31.1-1955) deals with gas transmission and distribution piping.

This code undertakes to define and specify the minimum requirements of construction of gas piping from the inlet to a gathering system or the outlet of a manufacturing plant through all the intervening steps to the outlet of the customer's meter. It defines as a gas service that pipe which runs between a main and a meter. It also defines high pressure as being a pressure greater than that supplied to a customer's appliance.

The code recommends that main connections be made at the top or side. On steel mains, connections may be made by welding or by using a service clamp or saddle; and on cast iron mains, connections may be made by drilling and tapping the main. The diameter of the tapped hole in cast iron pipe should not exceed 25 per cent of the nominal diameter of the pipe except that 1¼-in. taps are allowed in 4-in. pipe.

Concerning the service pipe, the code requires that steel pipe for all services less than 6-in. in diameter and that when cast iron is used for larger diameter services it should not extend through the building wall. Either welded joints or compression fittings should be used in all services. Cast iron pipe should never be threaded, but may be joined with caulked, mechanical, or flanged joints. A minimum cover of 12-in. in private property and 18-in. in streets and roads is specified for steel pipe.

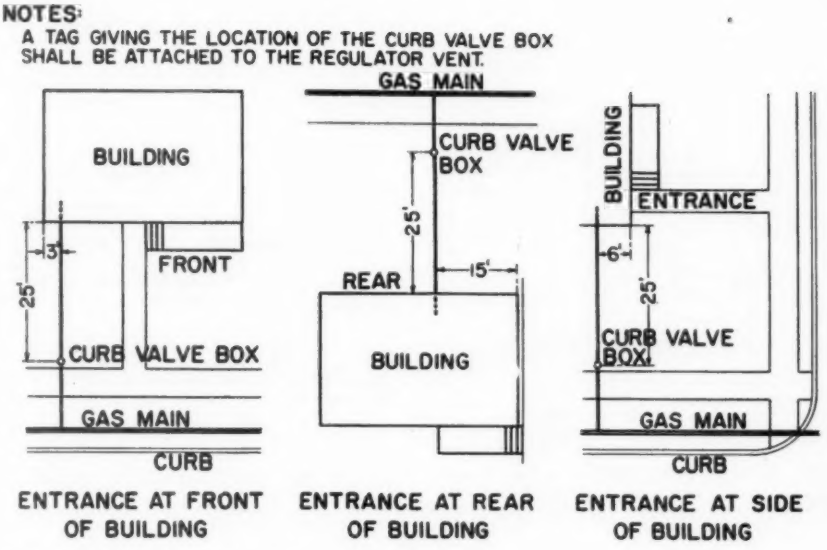


FIG. 7. Typical outside shutoff locations.

Service Facilities

Service shutoffs should be installed upstream of the meter and/or regulator. Outside shutoffs shall be installed on services operating at a pressure greater than 10 psig, on all services 2 in. or larger, and on all services supplying buildings where large groups of people assemble.

Underground steel services when installed below grade through the outer wall shall be encased in a sleeve or otherwise protected. The pipe or casing should be sealed at the point of entry. When it is necessary that a steel service be installed under a building it must be encased in a gas-tight conduit extending into a normally accessible part of the building where it shall be sealed.

Service regulators shall have breather vents and relief vents when required. Such vents shall terminate outside in rain and insect proof fittings.

Main Connections

The principal variable in the decision as to the type of main connection to make with cast iron mains is the size of main. The size of main generally limits the size hole that may be drilled and tapped without some sort of reinforcement.

Generally, it appears that with the exception of 4-in. cast iron pipe, the maximum tap diameter is 25 per cent of the main diameter. For 4-in. pipe a 1¼-in. tap is found almost as frequently as the 1-in. tap.

When the size or condition of the

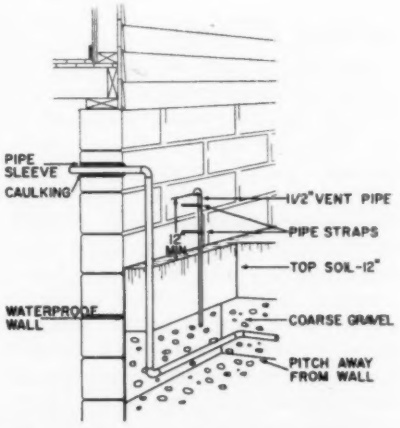


FIG. 8. Venting of service trench.

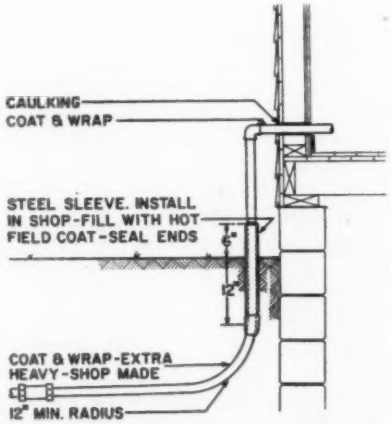


FIG. 9-A. Above grade service entrance.

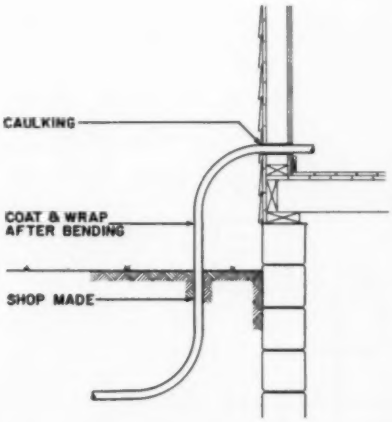


FIG. 9-B. Above grade service entrance.

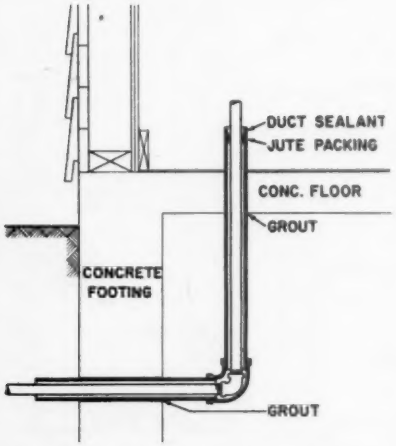


FIG. 10-A. Below grade service entrance.

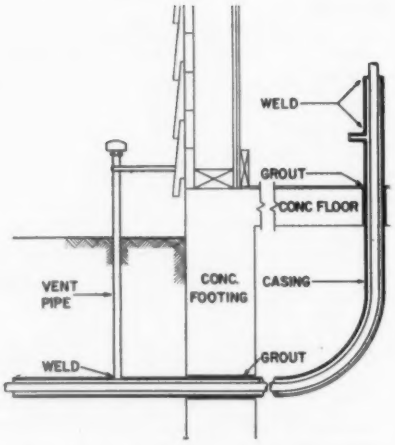


FIG. 10-B. Below grade service entrance.

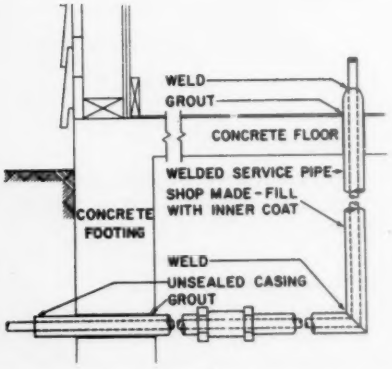


FIG. 10-C. Below grade service entrance.

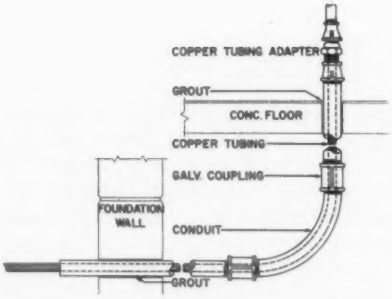


FIG. 10-D. Below grade service entrance.

main is such that a direct tap cannot be used, some means of reinforcement is required. There is some slight preference for a clamp over a sleeve.

Either single swing joints or rigid connections can be used. Malleable iron fittings are generally used, although brass fittings serve equally well. A wide range of coating materials can be used in field application to these fittings.

Main fittings are not usually insulated from cast iron mains, but the fittings are generally insulated from the service pipe.

The design of main fittings does not usually vary with design pressure. Where mains carry higher pressure, some type of shutoff is often used in the main fittings.

When tapping high pressure cast iron mains, the tap size is usually much smaller than the maximum allowed.

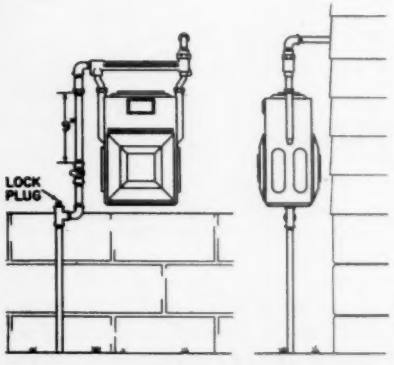


FIG. 11-A. Typical outside meter set.

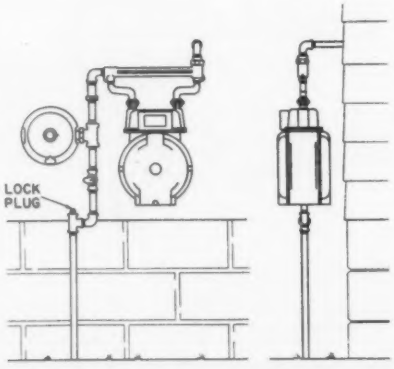


FIG. 11-B. Typical outside meter set.

Methods of Joining

In dealing with steel mains and services, welding is the preferred method of joining. Most companies connect fittings to mains by welding. Some make use of a saddle, while others make a joint with a compression or screwed fitting. The choice depends on pressure and individual preferences for types of materials used.

Since service pipe is not continuous, lengths must be joined in some fashion. Most companies specify welding, while some use compression or screwed fittings.

Service fittings are generally protected from corrosion, using grease, asphalt, or coal tar enamel coatings, generally with a glass wrapper or asbestos felt wrap. In some cases, a galvanized metal coating is used.

Cathodic protection is generally provided, and this is assisted by the fact that welded joints by their nature are electrically continuous. Where compression fittings are used, most companies use bond wire across the fittings to insure electrical continuity.

Service Installations

In most cases, the companies own the entire service installation.

Depth of service lines varies from 24-in. to 18-in. at the main, and generally is 18-in. deep at the building wall.

Some type of outside shutoff is required by most companies. These shutoffs are usually located between the street and sidewalk. Where there is an outside meter, the shutoff may be located above ground on the riser.

Building Entrances

Depending upon the design of the house and the gas service, the entrance into the building occurs either above or below ground. Mostly, the above ground entrance is associated with outside meter sets or basementless houses, and is not protected with anything other than the coating material. When the pipe enters the building wall it is protected either with a casing, or by being coated and wrapped. Some of the companies indicate that extra protection is unnecessary. Three of the companies install bare pipe.

The below ground entrance requires that a hole be drilled in the foundation wall large enough to accommo-

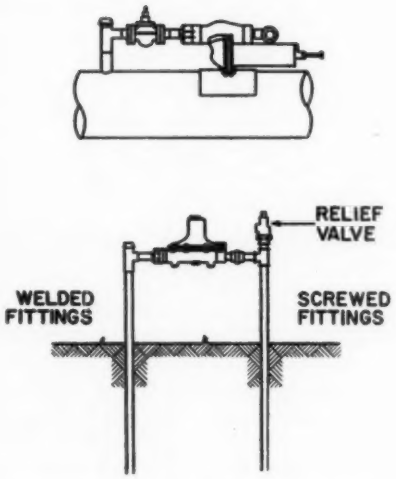


FIG. 12-A. Typical regulator installation.

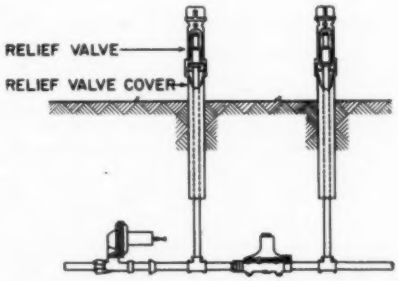


FIG. 12-B. Typical regulator installation.

date the service pipe. After the pipe or casing is installed it is sealed into the building wall with either a cement grout, some type of caulking materials, or tar.

Present building construction is tending to the basementless or slab type of building. Many companies do not allow gas service pipe to be installed in the crawl space or beneath the building, while others require that the service pipe be encased. Another way in which the problem can be circumvented is by running the pipe up the outside wall to the eaves, thence in the attic to the location of the drop to the meter set.

Swing joints are used on the service and are quite prevalent on inside risers. Cold bends are allowed by most companies.

Most of the companies insist on running the gas service the shortest distance from the main to the house. Almost as many, however, will permit the use of laterals in laying the pipe. The minimum distance between the building wall and a parallel service pipe is usually specified as one foot minimum distance.

Meter Installations

Few companies install no meters outside, while some install all of their meters outside. Outside sets are generally made because of the construction of the house, the pressure on the service, or if the customer desires an outside set. Many of the outside sets are protected by a metal, plastic, or wooden box.

Most companies that make inside meter sets have specifications as to the location of the meter and its relation to other utilities, heating equipment, and accessible locations.

Both tin-case and hard-case meters are used. The location of the meter, service pressure, and flow rate are reasons given for specifying one type of meter over the other. Generally, meter piping is all screwed fittings and an insulating fitting is often incorporated in the piping. This insulating fitting serves to separate the gas piping from the other underground utilities. The iron body brass core stop cock is the preferred shutoff for meter set use.

Regulators

When the distribution pressure is such that a pressure regulator is required it generally is incorporated in the meter piping. Generally, this service regulator has a ¾-in. body, an orfice from ¼ to ⅜-in. in diameter and about one-half are equipped with an internal relief valve.

The type of relief can be either a mechanical or mercury seal.

At some pressure levels two regulators are required to reduce the gas pressure to a utilization pressure. Most companies require double regulation when the pressure exceeds 50 psig. Since most of the companies do not permit a pressure greater than 25 psig inside the building, the first cut regulator must be located outside the house. The first cut regulator serves to cut the distribution pressure down to between 5 and 10 psig.

Relief valves are required on all services equipped with regulators by most companies. Some install relief valves on services supplying public buildings. Pressure is usually the criterion for specifying the use of relief valves.

Another safety device recently introduced is the pressure and/or temperature shutoff.

Other Materials

Many companies are investigating the use of some material other than steel for service pipe. Increased economics of construction and a longer useful life are the anticipated benefits to be derived from these studies.

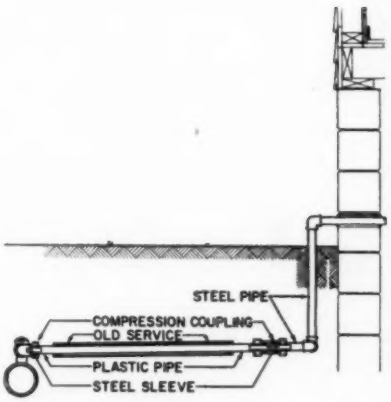


FIG. 13. Typical renewal by plastic insertion.

Copper has been used for several years by many companies for renewal by insertion in existing gas services. Some use copper for new services where difficult construction problems are encountered. Generally, the copper is connected to steel pipe with compression adapters and sweated or soldered joints are made to connect lengths of copper tubing.

Recent developments in plastics have led many companies to investigate the use of plastics for both new services and service renewals by insertion methods. Most of the companies are using a flexible type of plastic tubing although there is some experimental use of rigid tubing. Solvent welding is the preferred method of joining lengths of tubing and some type of plastic to steel adapter.

Service Maintenance

Generally, the preferred method of preserving service information is keeping card files by location, usually showing a sketch of the installation and a bill of materials. Only a few companies have a formal program of service replacement. The age of the service, failure of the service, and leakage survey are the principal reasons for service replacement. There is very little agreement on the anticipated life of a service but most expect at least 40 years.

Acknowledgement

This section prepared from a presentation given at the AGA Distribution, Motor Vehicle, and Corrosion Conference, Chicago, Illinois, 1956, by Messrs. B. E. Hunt, J. H. Erwin, and H. T. Libby, members of the AGA Gas Service Design task group.

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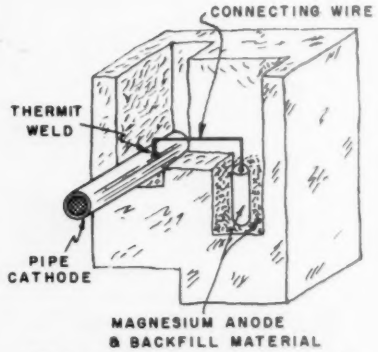


FIG. 1. Cathodic protection with single anode installation.

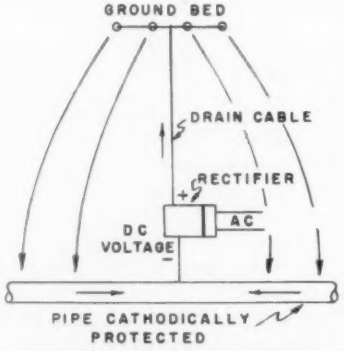


FIG. 2. Cathodic protection with single rectifier and ground bed (anode).

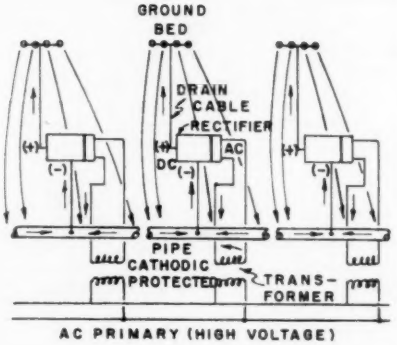


FIG. 3. Cathodic protection with distributed rectifiers with single ground beds.

Corrosion Control Methods

THE most common means of corrosion protection are coatings, extra pipe wall thickness, cathodic protection, and a combination of any two or all of these methods.

When a new line is laid today, all of these methods of corrosion protection are available and a choice of methods of corrosion control is usually based on economic factors.

The use of extra pipe wall thickness is rapidly decreasing because other means of corrosion control are now generally more economical. This is easily understood considering that the cost of pipe is based primarily upon its weight. Wall thickness is now usually determined by the design pressure of the line and little, if any, wall thickness is added to compensate for corrosive action of the soil.

There are many pipe coatings available today, and all are manufactured in accordance with high standards. These coatings* are more than paints; they are actually used to insulate the pipe from the soil. It is practically impossible to lay a pipe line so that no holidays exist in the coating after the line is backfilled. A holiday-free coating can be obtained by using certain types of detectors to go over the backfilled line, locating all holidays, then digging the line up to patch the coating. After this has been done, perhaps several times, it is possible that a line could be checked and found to be free of holidays. Such rigid coating requirements are uneconomical. Seasonal changes in the condition of the soils cause high stresses to be exerted upon coatings, which in time distort and weaken them materially.

Thus, a coating with absolutely no holidays immediately after construction, may in time contain a large number of holidays. If pipe passes throuvh corrosive soil, leaks will probably occur in these holidays within a very short time because the corrosive action is concentrated in very small areas.

A satisfactory and economical method of corrosion protection is to properly apply a good coating with suitable reinforcing wrappers, and then apply cathodic protection. Good quality coating, properly applied and carefully handled during installation and backfill, will keep to a minimum the number of holidays existing on the completed line. Total current requirements on such lines for cathodic protection are almost negligible. Cathodic protection costs are usually proportional to current requirements and the cost of applying cathodic protection to a well coated line is small, often less than two per cent of the cost of the coating. Applying cathodic protection to these lines gives the equivalent of a practically perfect coating — if the cathodic protection is properly installed and maintained so that it operates continuously.

Corrosion control on older lines, laid years ago when construction practices had not been developed, presents an entirely different problem. The following methods should be considered:

a. Repair leaks until pipe becomes unsafe to operate, then replace
b. Immediate replacement
c. Reconditioning
d. Cathodic protection

Methods (a) and (d) are most generally used. Replacement is expensive and is usually delayed as long as possible, provided the pipe is safe to operate. Reconditioning is usually as expensive as replacement.

In some cases, the most economical means of corrosion control is simply to keep leaks repaired until the pipe becomes unsafe to operate, then replace the unsafe sections. This is often true of small lines operating at low pressures. Once replacement is made, however, the problem of protecting the replaced sections becomes that of protectinv new pipe, and selection of a corrosion control method should be made on that basis.

The use of cathodic protection has increased enormously during the past 10 to 15 years. Its effectiveness has been well demonstrated over long periods by many applications. Savings effected by its application include:

a. Cost of leak repairs
b. Cost of reconditioning and replacements
c. Gas lost through leakage
d. Damages
e. Loss of goodwill
f. Loss of revenue.

Chief advantages of cathodic protection are the savings in gas lost and increased life of the pipe. These two items are difficult to accurately evaluate.

Pipe coating is one of the most effective means of corrosion control and it should be selected on a basis of proven quality and performance. The most important requirements for a good underground pipe coating are low moisture absorption (less than ½ of 1 per cent) and good resistance to hydrocarbons and soil stresses. Pipe coating should be disturbed as little as possible when repairing the pipe line. When damage to the coating cannot be avoided, it should be carefully replaced with the same type of coating or one having a similar composition.

To be effective, cathodic protection must be applied continuously. Experience has shown that cathodic protection units must be kept in operation at least 90 per cent of the time, and the closer this figure approaches 100 per cent, the more effective will be the results.

*The following section of this handbook — on pipe coatings — discusses them in detail.

Types of Cathodic Protection Equipment

Several types of cathodic protection installations are currently in use.

The common types are:

a. Galvanic anodes (Magnesium or zinc bars)
b. Rectifier units
   1. Isolated rectifier units
   2. Distributed rectifier system.

Galvanic Anodes

A magnesium (or zinc) bar buried with a special backfill in a hole near the pipe line, with a small copper wire connecting the bar to the pipe, is the simplest type of cathodic protection installation. It is called a galvanic anode because the current comes from a "galvanic" or chemical reaction between the magnesium and the soil, just as current from a dry battery is generated by reaction of the zinc can with the chemical in the battery.

In a dry battery no current flows until a circuit is provided by connecting a wire or other conductor between the carbon pole and the zinc pole. Similarly, no current flows from the magnesium bar until a return path is provided by connecting the wire from the pipe line to the bar. When so connected, current flows from the bar into the soil, is picked up on the pipe, and returns through the metal pipe and the connecting wire to the anode. Cathodic protection is received on the pipe where current is picked up from the soil. Several bars are generally installed in a group to produce more current than could be obtained from a single bar. By varying the spacing between the bars, the amount of current obtained can be controlled. It is important, when installing galvanic anodes, that they be properly spaced.

Rectifier Units

Rectifier type installations consist of equipment for converting power purchased from a commercial power company (usually 115-v a-c) into low voltage direct current required for cathodic protection. The positive (+) terminal of the rectifier is connected to a ground bed and the negative (–) terminal to the pipe. When the rectifier is turned on, it forces current through the ground bed into the earth, where it spreads out and is picked up on the pipe and is returned to the rectifier through the negative connection.

Selecting Proper Equipment

When the corrosion situation on a system is such that cathodic protection must be applied, the first thing to consider is the type of equipment that should be installed. Local conditions should be studied carefully as many factors will influence the selection. Equipment that has proved most economical at one location may not be suitable at another location.

What is the best type of cathodic protection installation?

The answer, of course, is that any type of installation will be as effective as any other type if it delivers sufficient current, is continuous in operation, and applies the current to the pipe where it is needed. There may be a considerable difference in the cost, however.

One ampere, applied to a pipe line, provides the same amount of protection regardless of where the current comes from. It makes no difference how many volts are required to push the current through the circuit. For example, a rectifier with a poor ground bed might be set at 4-v to push one ampere through the ground bed, into the earth and to the pipe. With a good bed, only ½-v at the rectifier might push one ampere through the circuit. The line receives the same protection in either case, although power costs would be higher in the first case.

An important step in selecting cathodic protection equipment at a new location is to estimate as accurately as possible how much current will be required to protect the section under consideration. Often it is necessary to rely on past experience, using records of units previously installed, to make a reasonable estimate of current requirements.

Three factors influence how much current a pipe line will require for protection:

a. Type and condition of pipe coating
b. Area of pipe
c. Environment.

Bare pipe can be completely protected but a heavy current is required (30 to 80 amp per mile of pipe depending on diameter and environment). A well coated, new pipe line usually takes only a fraction of an ampere per mile, even with large diameter pipe. Over a period of time, as the coating deteriorates, more current is required for protection. Even a poor coating, by present day standards, has been found to reduce current requirements considerably.

The second factor is fairly obvious. The larger the pipe diameter, or the longer the section to be protected, the higher the current requirement will be.

The third factor, environment, probably affects current requirements less than the first two factors, but soil type, drainage, type of backfill, proximity to other metallic structures, and other environment factors must be considered.

Equipment for Protecting New Pipe

New pipe with a good coating presents no appreciable problem from a cathodic protection standpoint. A relatively small current will protect several miles and a good coating causes the current to spread out effectively, so that the current source can be located almost anywhere along the line with equal results. Galvanic anodes weighing about 17 lb per bar generally produce about 0.1-amp each and last about 10 years with practically no maintenance. They cost from $12 to $25 each installed, depending on local conditions. New pipe can thus be protected for an estimated 10 years with a total outlay of some $50 to $150 per mile. Whether magnesium or zinc is selected depends on local conditions. Zinc is very effective in low resistant soils. Being lower in the electrochemical series than magnesium it has a lower driving potential, an advantage when the pipe to be protected has a low initial pipe-to-soil potential, since it automatically prevents excess current being expended to build up pipe-to-soil potentials in excess of requirements. On the other hand, this low driving potential is a disadvantage in high resistant soil, as it limits the output obtainable. The high driving potential of magnesium makes it very desirable for use in high resistant soils and applications where initial pipe-to-soil potentials are high.

If commercial power is available at some convenient point, a single small rectifier might be installed instead of galvanic anodes. More flexible output adjustment is obtainable with the rectifier, and if soil resistance is high, the necessary higher driving potential can be easily obtained. Initial cost of a small rectifier installation should be between $200 and $500 with an annual operating cost of $100 to $200. It can be expected to protect 10 miles or more new pipe line, depending on quality of coating and environment.

Protecting Bare or Poorly Coated Pipe

Large diameter bare or poorly coated pipe line may require 30 to 80 amp per mile for protection. Current does not spread out readily on such a line and less total current will be required if current is applied at many points along the line as can be done with a distributed rectifier system or with galvanic anodes well distributed along the line. If the average current requirement for such a pipe line were 60 amp per mile, approximately 600 galvanic anodes would be required per mile. At $12 to $25 each, initial cost is relatively expensive even if the full 10 years life can be realized from the anodes.

A distributed rectifier system having the same capacity of 60 amp per mile, could be installed at much less expense.

Guide To Protective Coatings For Pipe

THE cost of pipe protection represents a sizable figure in the total installation cost of pipe. The value of the protective coating as a barrier between the metal and the environment is only equal to the materials used, the method of application and the final inspection of the finished job.

Because of the value of the coating it would be expected that the company installing the line would use every precaution to see that the line is installed properly. This however is not the case. Many installations are completed without any or with very poor inspection with the result that the line would probably have lasted longer if it had been installed bare. Some of the poor jobs can be traced to the lack of knowledge of the proper type of coating to be used, poor control of coating temperature, poor pipe cleaning operation, applying the coating over dead primer, careless handling of the coated pipe after being coated, during lowering in and backfilling operation.

In the last several years, manufacturers of coating materials have so improved their product that the coating can in effect be tailormade for the application for which it is to be used. Thus we can secure a coating for greater range of atmospheric temperatures, plastic tapes of one type that can be secured for applications between 40F and 200F while another type of plastic tape can be secured for application between 0F and 200F.

Coatings for underground applications may be divided into three general classifications and can be further broken down as to material and source.

1. **Bituminous.**
   a. Coal tar from the distillation of coal.
   b. Asphalt from the distillation of oil.
   c. Asphalt from natural asphalt beds.
2. **Waxes and greases.**
   a. Heavy consistency grease from the distillation of oil.
   b. Wax from the further distillation of oils.
3. **Plastic tapes.**
   a. Polyethylene from acetylene gas and hydrogen chloride.
   b. Polyvinyl chloride, from acetylene gas and hydrogen chloride.

So that the coatings of different manufacturers but similar characteristics may be held within certain limits a series of tests have been developed. A brief resume of the various terms and what they mean will be given.

Melting Point

When heat is applied to pitches and asphalts and enamels made from them, the material does not pass suddenly from a solid state to a liquid state. A gradual softening of the pitches takes place as the temperature is increased becoming fluid only after passing through several stages of gradually increasing softness. The melting or softening point in both coal tar and petroleum industries is used as a gage of the consistency or hardness of the pitches and certain compositions made from them. The following is of importance in securing a coating for desired results.

1. High melting point bases and low filler content offer maximum resistance to soil stress or pressure deformation.
2. Low melting point bases and high filter content are less resistant to slide or sag.
3. Generally bases having a high filler content are of lower melting point and are not highly resistant to soil stress or pressure deformation.
4. In a given melting point range the compounds having a lower filler content can be applied at lower temperatures and are not subject to large evaporation loss. In contrast the higher filler content compounds may suffer a greater loss by evaporation.

Flowability

This can be stated as the application temperature required to secure a good flow and a given thickness of coating.

In field application the temperature of the agitated enamel is watched carefully and the thickness of the applied coating checked with a pit depth gage to make sure that a coating thickness of 2/32-in. or 3/32-in. is secured. The atmospheric temperature will control to a great extent the application temperature of the enamel. This condition will affect practically all enamels and can only be checked by the pit depth gage where the temperature varies during the applications period.

Evaporation Loss

It should be understood that most enamels contain volatile liquids that will evaporate from the enamels if the heat is held to a high level for a considerable period of time. If the coating is held at a temperature above that recommended by the manufacturer the flexibility will be lost and the enamel will become brittle. It must be under continuous agitation to prevent coke formation. If this should occur the entire batch is generally discarded.

Soil Stress

When a pipe line is installed in the earth and covered with backfill it is subject to mechanical forces generated by its contact with the bottom of the ditch and by expansion and contraction of the soil as it passes through wet and dry stages. The metal is of sufficient strength to resist such mechanical stresses under ordinary conditions. The materials used to protect the pipe from corrosion do not have this strength so the soil will act upon it. To prevent excessive damage a wrapper is applied over the enamel and bonded to the enamel. In so doing it is often possible to eliminate the damage caused by soil stress. The addition of the wrapper also reduces damage caused by abrasion and reduces the penetration of small stones that are in the bottom of the ditch.

Water Absorption

It is generally conceded that corrosion of underground pipe would not exist if moisture is prevented from contacting the metal. If the coating waterproofs the pipe it also prevents contact of the metal with its environment which may contain acids, alkali and other contaminants which could adversely affect the metal.

Ash and Filler Content

The mineral content of most pipe line enamels results from the intentional addition of minerals of various kinds during the manufacturing process. The ash or filler content of itself is of little significance until it is correlated with other data.

Slide or Sagging Tendencies

In construction work it is sometimes necessary to allow the coated pipe to remain on top of the ground for a period of time before installation. During this time the pipe is exposed to the heat of the sun and to atmospheric temperatures that may approximate the melting or softening point of the tar. When such a condition exists the coating will tend to slide or sag, reducing the thickness of the coating on the top of the pipe to such an extent that its

Adapted from paper by N. P. Peifer, Corrosion Engineer, Manufacturers Light & Heat Company, before the AGA.

value as a protective coating is greatly depreciated. In selecting an enamel this condition must be taken into consideration.

Primer will not stick to a dirty, wet or rusty surface and for this reason it is necessary that the pipe be clean before the primer is applied. In some instances the cleaning may be accomplished by the use of cutters and wire brushes. In others where the pipe has a heavier rust film it may be necessary to sand or grit blast the metal surface before the primer is applied.

A good bond cannot be secured if the coating is applied over a primer that has been applied over mill oil or lacquer, it has been found that a good bond is not secured. In fact, during warm weather it is sometimes possible to roll the coating off the pipe when it has been applied over the mill oil.

Primers will gradually lose their volatile liquids after they have been applied to a metal surface for a period of time because of evaporation. The primer is said to be dead when this occurs and if enamel is applied over a dead primer it will not bond. The period of time after application before the primer becomes dead depends upon the heat and humidity of the air. The best test for a dead primer is to see if it will flake off when the fingernail is scraped over it. When this occurs the cleaning machine is run over the pipe and it is again primed.

There are several manuals published by the coating manufacturers that will explain the general procedure when the pipe is coated either in the mill or over the ditch. The following paragraphs will give some of the conditions that have been noted during actual procedure and are not in the manuals.

A considerable number of faults are picked up by the jeep as soon as the coating machine kicks off. These may be relatively close together for a hundred feet or more. Look for:

Dust. Dust on the primer will cause jeeps.

Moisture. Most if not all primers contain a small amount of moisture. When the percentage exceeds 1 to 2 per cent it will cause a considerable number of jeeps. This condition will continue as long as the primer is used. The faults look like craters with the bare metal exposed at the bottom. The pits are most frequent on the top and side of the pipe close to the top where the enamel is at its highest temperature. The remedy is to secure new primer.

Coke. When a coating machine is made ready for use it is customary to heat all the parts with a high temperature torch. During this operation the material from the last operation may change to coke. This will flow with the coating when the machine is put into operation. The particles of coke will cause the coating to jeep. If it does not clear in a short time check the kettles to make sure the coating has not formed into coke. Never depend upon the thermometers in the coating kettle. About one in a hundred are correct. Check with a portable thermometer.

Mechanical Faults

When the coating machine is put into operation some parts of it may rub the pipe causing the enamel to be either too thin or be removed. This can be checked by watching the machine. In flood coating types the iron is often found to rub. This is apparent when the faults occur on either up or down grades.

Solvent Faults

As the coating runs to the coating machine from the kettles it is giving off fumes. This is some of the volatile liquids evaporating because of the heat. This solvent will gather on the frame of the coating machine and drop off on the coated pipe. When the jeep passes over these spots they will show a fault in the coating. The remedy for this condition is to keep the machine clean. In doing this keep this solvent off the skin.

Faults Covered by Wrappers

Asbestos felts as used for pipe line wrappers will absorb a certain amount of moisture. If the moisture content becomes too high it will cause a steam to form when hot enamel comes into contact with it. When the steam is trapped under the wrapper it will cause a blister which will blow the enamel from the pipe surface. At times this can be observed by wisps of steam given off at the wrapper surface. The remedy for this is preventive. Keep the felt in a good storage room with a good roof and keep the felt from contacting the dirt or cement floor. If it becomes too bad the felt will have to be discarded.

If the material used to saturate the felt contains too much naphthalene, the naphthalene will tend to form on the surface of the felt in the form of white crystals. The naphthalene crystals will evaporate when the heated enamels contact them and form a gas that may affect the enamel in a manner similar to steam. It may also cause a sufficient loss of solvents to cause the saturating material to become brittle causing the felt to break readily when it is being used.

Mill Coated Pipe

When hot enamels or waves are applied at a coating mill the conditions under which they are applied are much more favorable than over the ditch or yard applications. Moisture and dust on the pipe to be coated is seldom if ever encountered. The asbestos felt wrappers used over the coatings are stored under conditions that preclude an excess of moisture being absorbed. Even though these conditions do not exist, faults in the coating will occur making it necessary for the applicators to test the coated pipe with high voltage electricity to expose the faults. Because a paper is used as a packaging material for the pipe it is customary to use a higher test voltage than would be used for an over the ditch coating. This is because of the dielectric of the paper which is added to that of the enamel and the felt.

Most of the difficulties encountered with mill coated pipe is during the unloading, stringing and bending operations. Protection of the pipe at the welds often presents a considerable problem. Hot enamel, rubber tapes and plastic tapes are used for joint protection.

Grease Coatings

The chief constituent of a grease type coating material is petrolatum obtained from the residue of the distillation of paraffin base crude oils. The consistency of the grease is controlled by the distillation process or by the addition of mineral fillers.

Some of the greases can be applied as a cold coating during warm weather but have to be heated when the weather becomes cold. Grease coatings are sometimes applied over rusty metal but it is believed that if a good coating application is desired the pipe should be cleaned of all dirt and rust.

Grease coatings should never be installed in a dry soil unless a wrapper is applied to prevent the soil from contacting the grease. Where this is not done the grease becomes diffused into the soil by osmosis with the result that no coating remains on the pipe. In some soils or waters there may be a tendency of the material to saponify. The electrical resistance of a grease type coating is low even though a wrapper is used.

Wax Coatings

The base materials for wax type coatings are obtained from the distillation of paraffin base crude oils. The melting point is in the same range as asphalts and coal tar pitches.

Waxes are applied to the pipe at the coating mill and over the ditch by the travel liners. Wrappers are used in conjunction with this coating. They include plastic tapes and a form of tobacco cloth with an acetate backing. Asbestos felts are also used, in which case they are not saturated with either asphalt or coal tar cut backs. The wrappers are bonded to the wax during the application procedure and the entire coating is tested with high voltage electricity in a manner similar to that

used for hot applied asphalts or tars. The potentials used are of the same value as used with other types of coatings.

Plastic Tapes as Pipe Coatings

While pastic tapes have been in use for a considerable period of time in the electrical industry they have only recently come into use as a protective coating for underground and overhead pipe lines. Their source is the chemical plant although their base materials are a natural product.

Characteristics of polyethylene and polyvinyl-chloride films.

Material	Poly-ethylene	Polyvinyl-chloride	
Thickness overall	12 mils	10 mils	20 mils
Tensile strength lb per in. width	25	25	60
Elongation at break	80%	175%	250%
Adhesion to steel per in. width in ounces	60	25	20
Adhesion to backing, oz.	40		
Water absorption rate %.	.02	.19	57
Water vapor transmission rate (grams/100 sq in./24 hr)	.20	1.55	1.21
Dielectric strength, volts.	14,000	10,000	22,500
Insulating resistance (meg. ohms)	1,000,000	200,000	200,000
Application temperature			
Low	Zero F	30 40 F	
High	200 F	200 F	

These materials are calendared into a film but only the polyethylene and the polyvinyl-chloride are used as a pipe protection material or film. During the calendaring process a pressure sensitive adhesive is applied to one side of the film.

It should be noted that the film thickness of both materials is eight mils, the polyethylene tape having an adhesive four mils thick making a total thickness of 12 mils while the polyvinyl-chloride tape has an adhesive thickness of two mils making a total thickness of 10 mils. The additional thickness of the adhesive film is important where the surface to which it is to be applied is rough, permitting the adhesive to extend to the bottom of the rough area thus securing a stronger bond.

When a plastic tape with a pressure sensitive adhesive is to be applied to a pipe line it is essential that the metal surface be free of rust, dirt and dust. For this reason it has been found good practice to apply a primer to the metal surface just prior to the tape application. It has also been found advantageous to apply an additional wrapper over the 10 to 12 mil tape as an additional protection against abrasion. Tar or asphalt saturated asbestos felt wrappers may be used for this purpose. They are not bonded to the tapes and only act as an abrasion resistant wrapper.

Reinforcing Materials

In this classification will fall the various materials that are used to reinforce hot applied coatings by becoming an integral part of the coating or a wrapper that is bonded to the enamel so that a greater resistance to sag and penetration is secured. In the latter case they also act as a shield against backfill.

Asbestos Wrappers

The general term for wrappers of this type is asbestos felt and they are composed of a mixture of asbestos and rag combined together with a binder and saturated with either an asphalt or tar cutback. The rag content of the felt wrapper will vary between 10 to 25 per cent while the asbestos will be either long or short fiber type. There is a tendency for this wrapper to pick up moisture if it is not stored under proper conditions. This becomes apparent when a vapor is formed during the application when the hot enamel comes in contact with the felt. If the vapor is trapped under the wrapper it will form a bubble in the coating leaving a weak spot that will eventually cause a failure at this point.

The wrapper is applied directly over the hot enamel as it is flooded or sprayed on the pipe, in this manner becoming tightly bonded to the enamel. The tension of the wrapper should be so adjusted that it does not pull through the hot enamel and come in contact with the metal surface. This can be accurately checked by cutting out a section of the coating at the lap in the wrapper and making a physical examination. It is often indicated by the size at the bead formed at the lap in the wrapper. If the bead is of considerable size it may indicate that the felt has been pulled in too tight squeezing the enamel out at the lap. Excessive tearing of the felt during the application will indicate too much tension or it may be caused by evaporation of the volatile liquids out of the cutback used to saturate the felt.

The formation of white crystals on the surface of the felt is indication that the naphthalene has evaporated from the cutback and formed naphthalene crystals. When the wrapper becomes heated by contact with the hot enamel these crystals will evaporate or form a gas. Whether this gas will harm the coating is not known but since there is a chance that it may cause trouble care should be exercised in its use.

Ordinarily a 15-lb felt wrapper is used as an outerwrap with hot enamels. However, in the last few years a wrapper having a weight of only eight pounds has been developed. To keep this wrapper from tearing excessively it has been reinforced by the use of glass threads running parallel with the wrapper. While this wrapper has the strength of the 15-lb felt it is questionable if it has the abrasion resistance.

Care should be used to secure the right wrapper for the enamel that is to be applied. Thus, if a coal tar enamel is to be used the wrapper should be saturated with a coal tar cutback and when an asphalt enamel is to be used a wrapper saturated with an asphalt cutback should be used.

Glass Outer Wrap

Glass outer wrap is a thick film of glass fibers saturated with a composition of tar and asphalt cutback. It is applied in the same manner as asbestos felt over the hot enamel coating.

Paper Outerwrap

When pipe is coated at a coating mill a paper outerwrap is applied over the felt wrapper to protect it during shipment and handling. On some over-the-ditch jobs it has also been used. In this case it is probably used to resist the damage caused by backfill. Paper has a relatively short life when it is installed underground because of rot and bacteria action. Paper should not be applied over and bonded to the enamel. If the pipe is exposed to alternate wet and dry periods it will tend to shrink and in so doing pull the enamel away from the metal.

Glass Inner Wrap

Glass in the form of a single filaments laid down in a randon form and bonded together with some type of bonding material is formed into a wrapper that is used with hot enamel applications. Sufficient tension is applied to this wrapper to pull it into the enamel but not through the enamel to the metal surface. This is said to add strength to the enamel and reduce the tendency to sag and offer more resistance to penetration. Care should be exercised to make sure that the glass filaments are completely saturated with hot enamel. Unless this is accomplished it is possible for capillary action to draw water into the enamel where the glass is exposed.

Rockshield

This material is made from scraps from the manufacture of asbestos roofing etc., and is formed into sheets of different lengths, widths and thickness and is used as an additional shield around the coated pipe where a considerable amount of rocks are encountered in the backfill or where the pipe will be handled roughly because of the terrain. Because of its thickness it cannot be wrapped around the pipe but is installed in the form of sheets that are fastened around the pipe with steel strappings or by use of glass filament tape with an adhesive. ★ ★ ★

Determining Regulator Capacities

A study of the various equations now in use for computing regulator capacities reveals the following seem to be the most practical:

(1) Where the flow is below critical velocity (regulator outlet absolute pressure being more than one half of the regulator inlet absolute pressure): $Q = K\sqrt{h\,p_o}$

(2) Where the flow is above critical velocity (regulator outlet absolute pressure being less than one half of regulator inlet absolute pressure): $Q = \frac{1}{2}\,KP_1$

Where,

Q = Mcf per hour of .65 sp. gr. gas at a base pressure of 14.73 psia

h = Drop in pressure across regulator, psi

P_o = Outlet pressure, psia

P_1 = Inlet pressure, psia

K = Constant, depending on regulator valve size and characteristics.

For convenience, these equations are transposed as follows:

$$Q = K \times \text{Flow Factor}$$

Graphic charts (Fig. 1 through 6) have been prepared whereby flow factors may be read directly, depending upon the regulator inlet and outlet pressures.

The "Flow Factor" (shown on bottom scale) is equal to $\sqrt{hp_o}$, for conditions outlined under equation (1); and is equal to $\frac{1}{2}\,P_1$, for conditions outlined under equation (2).

These flow factors when multiplied by factor "K" (in table) equal the recommended maximum regulator capacity.

From Columbia Gas System Service Corporation.

In attempting to determine "K" factors for practical use for the different regulators in common use, it is necessary to make several compromises and assumptions which are briefly stated as follows:

(1) It is interpreted that the maximum capacity of a regulator is that quantity of gas which a regulator will deliver at a given pressure drop between its inlet and outlet flanges; that is, the regulator body is considered the unit rather than only the regulator valves or any part of the setting.

(2) In developing practical "K" factors for the different regulators, it was found that some regulators have greater valve opening areas than the area of the regulator outlet pipe opening. In such cases, the "K" factors shown in the table are measured to an amount that has been found practical.

(3) These capacity data are based entirely on the capacity of the regulator main body and do not take in account variations in outlet pressure resulting from other causes, such as friction, lack of operative power, etc., which are common in the older type of regulator.

The table sets forth practical "average values" for K, which are believed to be accurate and safe for the purpose intended. In most instances they are as accurate as many of the other variables involved, such as the estimated inlet and outlet pressures, etc. Where more accurate values of "K" are available, such as those furnished by regulator manufacturers, obtained from special tests, etc., they may be substituted for those in the table and inserted in the blank spaces provided.

HOW TO DETERMINE REGULATOR CAPACITIES

The following curves and table of "K" factors are a convenient way of determining the capacity of various kinds of regulators. The "K" factors shown are for commonly used types of regulators.

To determine maximum capacity of regulator.

1. Locate outlet pressure on left margin of graph.
2. Trace horizontally to estimated minimum inlet pressure.
3. Trace vertically down and read "Flow Factor" on bottom scale.
4. Maximum hourly capacity equals "Flow Factor" multiplied by "K" factor of type regulator considered.

Example:

Assume: A 6-in. balanced valve, regulator of the older type using flat disc seats, 0.25 psi outlet gage pressure and an estimated minimum inlet gage pressure of 10 psi.

from Fig. 1 — Flow Factor = 12.1

from table, "K" factor = 16.5.

Maximum Regulator Capacity = 12.1 × 16.5 or 199.7 Mcf per hour

To determine the size regulator required when the quantity and pressure conditions are known.

Example:

Assume: A maximum hourly rate of flow of 100 Mcf per hour, an outlet pressure of 100 psi, and an estimated minimum inlet pressure of 250 psi.

Then: From Fig. 4, Flow Factor = 133; therefore "K" Factor required = 100 + 133 or .75. It will be noted from table of "K" factors that a 2-in. regulator having 1-in. balanced valves will have ample capacity.

TABLE OF "K" FACTORS.

Pipe size of regulator	Inner valve	"K" Factors
2 in.	⅞ in. Balanced valves	.5
2 in.	1 in. " "	1.0
2 in.	Std. " "	1.9
3 in.	" " "	4.2
4 in.	" " "	7.5
6 in.	" " "	16.5
8 in.	" " "	27.5
10 in.	" " "	42.0
12 in.	" " "	61.0

These "K" factors are used for the older type regulators using flat disc seats, quick opening regulators limited to ¼-in. valve travel, and for the newer design regulators where the outlet piping is not increased immediately at the regulator.

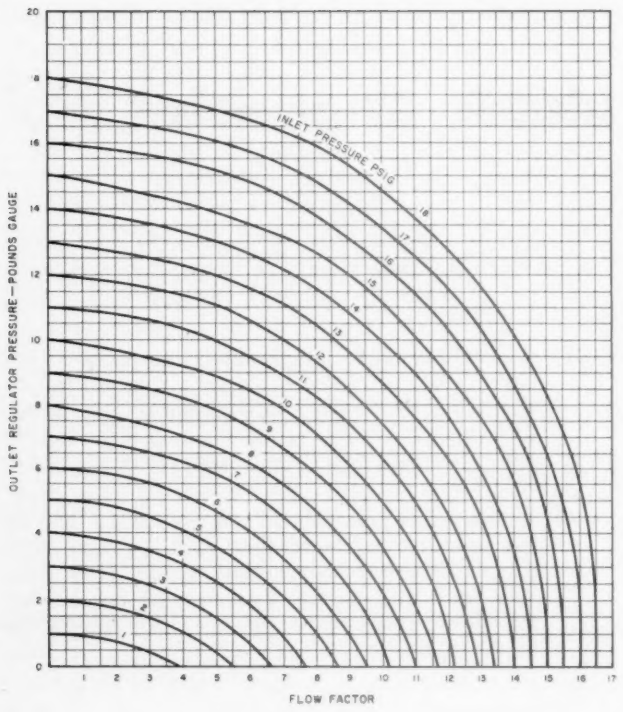


FIG. 1

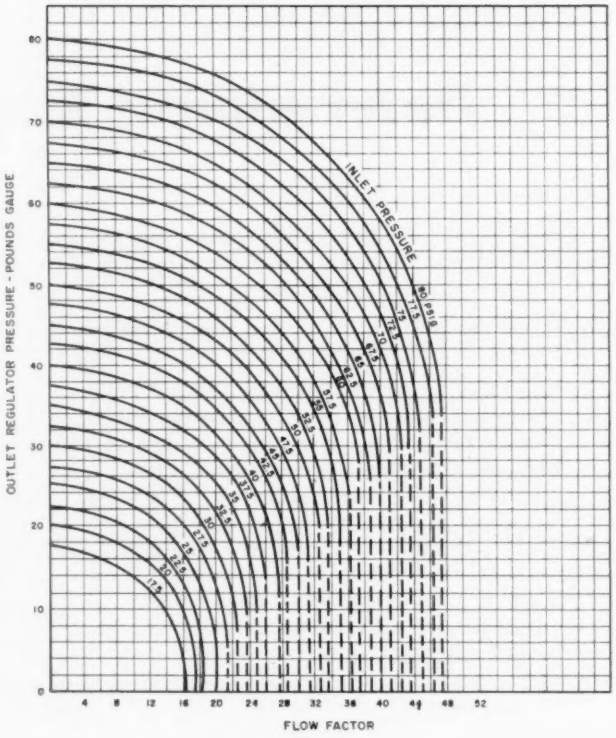


FIG. 2

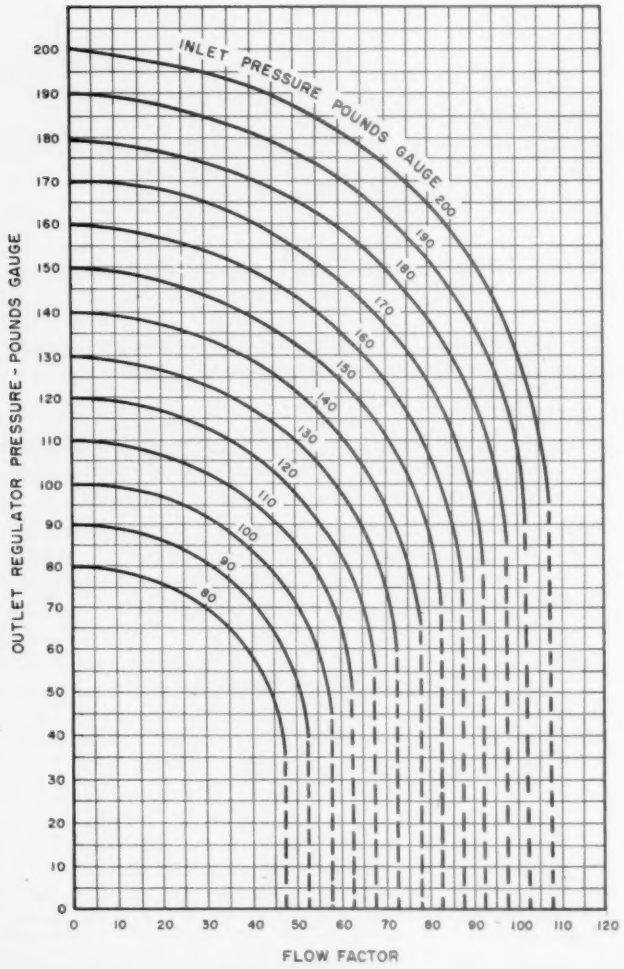


FIG. 3

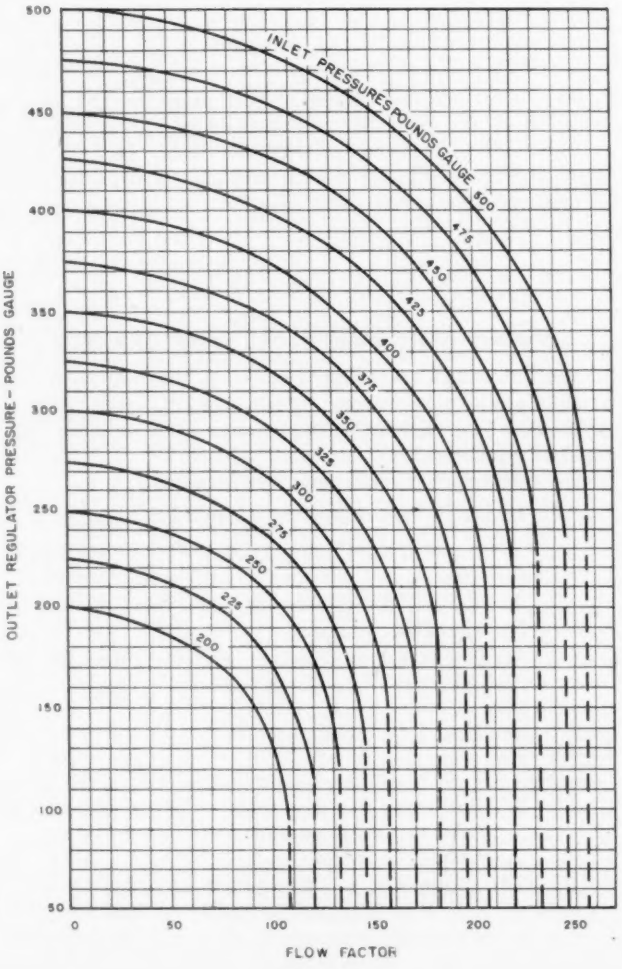


FIG. 4

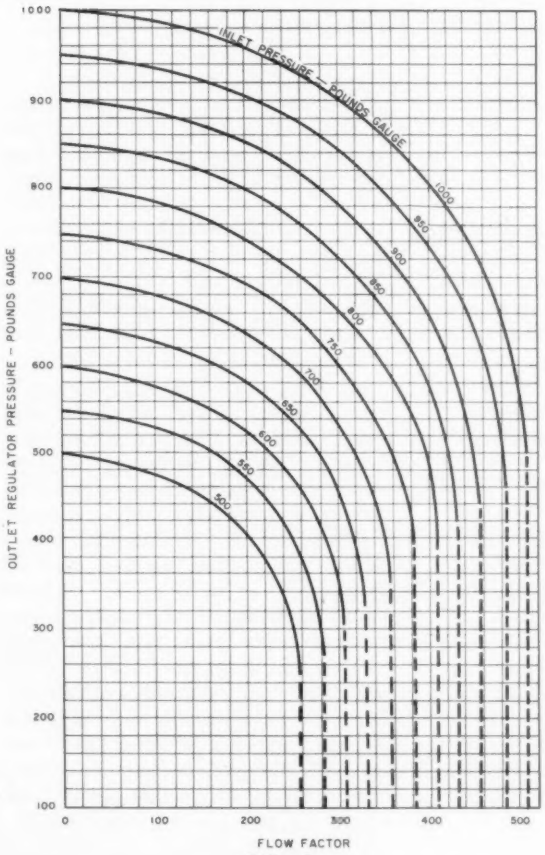


FIG. 5

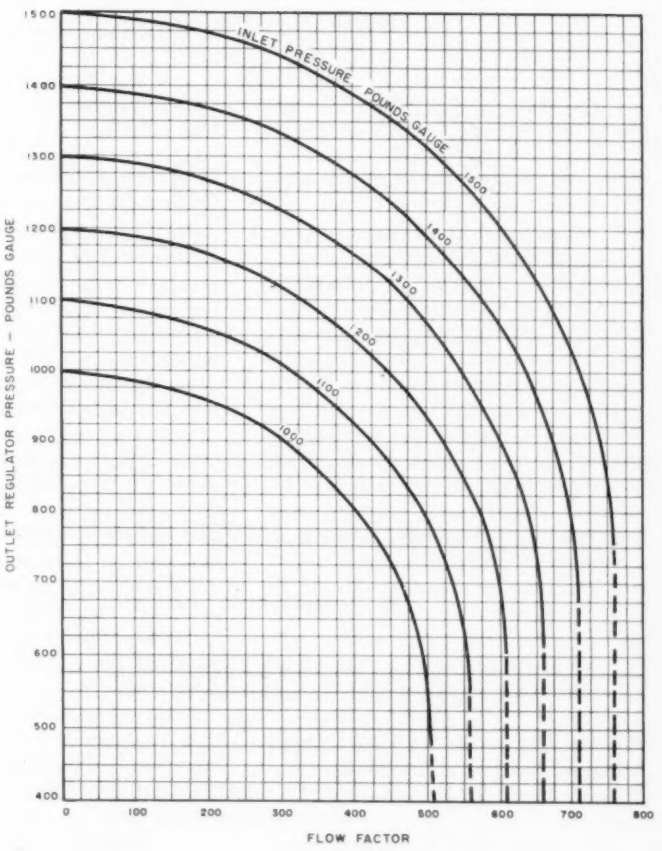
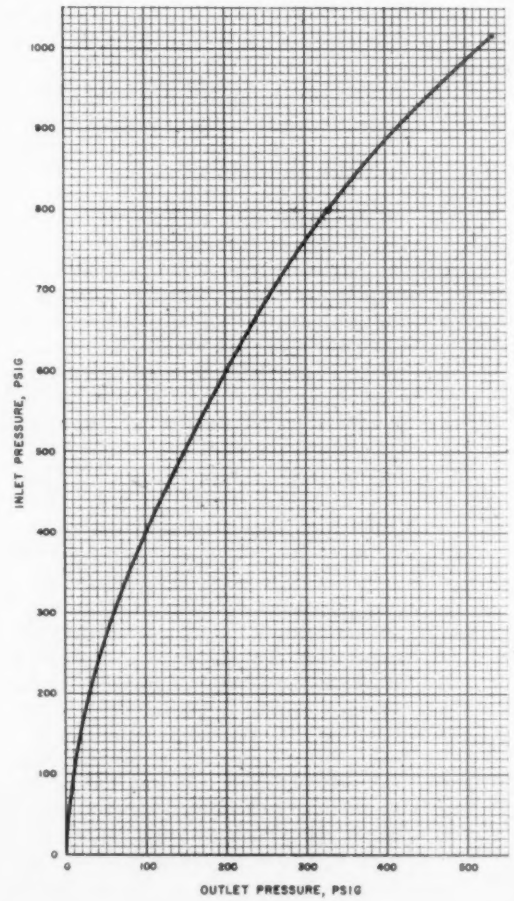


FIG. 6



HOW TO DETERMINE THE NUMBER OF REGULATORS IN SERIES — INCLUDING MONITORING REGULATORS —FOR GIVEN PRESSURE CONDITIONS.

(This does not apply to service regulators).

Explanation:

Case 1: Determine the practical pressure cut for a 700 psig inlet pressure.

1. Locate 700 psig inlet pressure on the left scale of the graph.
2. Trace horizontally to the right to the curve and then trace downward to the bottom scale. Read outlet pressure of 250 psig.

Case 2: Determine the number of cuts required for station where the inlet pressure is 700 psig and the desired outlet pressure is to be 20 psig.

First Cut: 700 psig to 250 psig

Second Cut: 250 psig to 50 psig

Third Cut: 50 psig to 20 psig

NOTE: While the example shows pressure cuts, the same number of regulators may be used, with one or more regulators being used as monitoring regulators.

From Columbia Gas System Service Corporation

How To Solve Regulator Freezing Problems

The reduction of pressure of a gas caused by throttling through a pressure reducing valve establishes a sudden expansion of gas at the outlet of the valve. This sudden expansion sets up a heat transformation, causing the valve body and pertinent piping to be the absorber. Whenever this heat is not sufficiently present in the gas itself, then it must be taken from the immediate environment. In this case, it is the valve body, immediate piping, and soil, if pipe is covered. The temperature reduction for a typical natural gas is approximately 1F for each atmosphere reduction or 7F per 100 psi pressure cut. The effect of this heat transfer problem manifests itself in many ways and can be a source of serious trouble. The two most important problems involved are, (1) internal freezing of the regulator, and (2) external freezing of the regulator body, the immediate piping and the surrounding environment.

Internal Freezing of Regulators

Internal freezing of a regulator occurs when the temperature drop (due to a pressure reduction) causes the gas temperature to reach the dew point of the gas. When this condition is reached, problems can occur from hydrate formation, or ice formation, if the dew point is below the freezing point.

The freezing point depends on the gas composition, water content, and pressure of the gas. There are several methods of combating these problems, such as alcohol injection, heated buildings, and heat exchangers.

Freezing of Surrounding Outlet Piping

The low gas temperature caused by large pressure reductions frequently has serious effects on regulator outlet piping and mains. When the temperature of the outlet gas and piping is 32F and below, freezing of the moist earth covering the pipe causes expansion and heaving. Usually, this action results in damage to building foundations, highways, etc., and imposes high stresses with possible distortion to the piping and regulator setting. On a regulator setting where the maximum flow rate and/or pressure cut is not large, this effect may be unimportant; however, on large regulators with high maximum flow rates, and especially in poorly drained areas, serious damage may result.

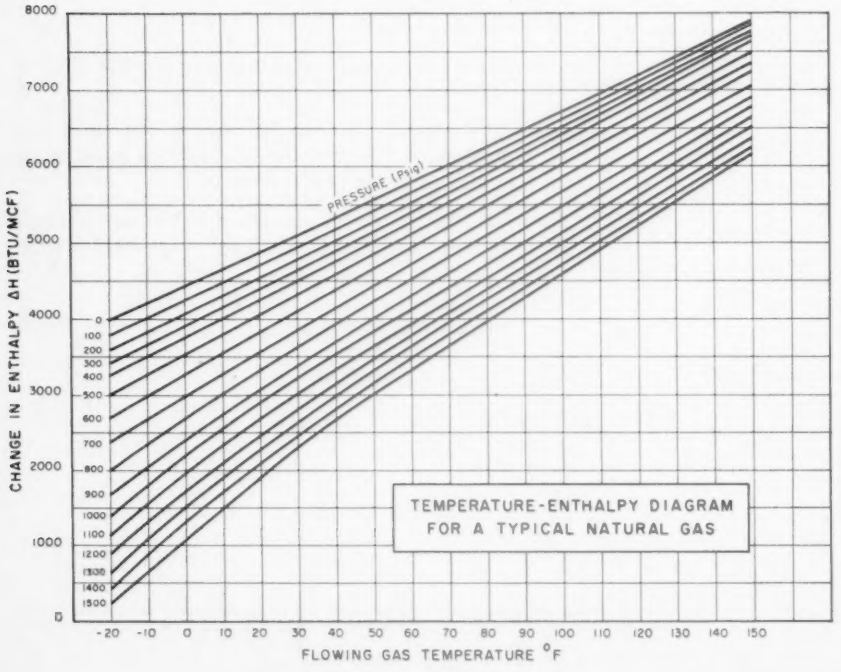
Best experience, to date, indicates that one of the four methods (or a combination of all four in some troublesome locations) may be used to eliminate damage.

1. One method commonly used is to have all underground piping that carries cold gas at 32F or below, surrounded with at least two feet of loose gravel. Care should be given that proper drainage is provided to remove free moisture from the gravel. Particular attention should also be given the corrosive properties of the gravel used.

2. When the regulator setting is in a location that is flat and low without opportunity for drainage, the setting and piping may be elevated above ground or station flooring and outlet piping extended for some distance from the station before being buried. This distance is governed by the surroundings such as railroad crossings, road crossings, or building foundations, and physical limitations of the property.

3. Another method is to insulate the pipe in order to slow down the heat transfer between the pipe and the surrounding earth. Generally, the pipe would be insulated in the immediate vicinity of the regulator where damage may occur, e.g., if the pipe passes under the structure walls, a railroad crossing, or any highway, etc., the pipe would be insulated so that any freezing that might occur will take place well away from the zone where damage may result to the structure or highway. One method of insulation is a sealed casing on which a partial vacuum has been established.

4. If regulator settings are in a location where none of the above methods can be used, then some method of applying heat can be used. Some type of heat exchanger should be installed on the inlet to the regulator setting in order to heat the gas so that it will be above 32F on the outlet of the regulator setting. In a setting of this type, the cost of fuel required for operation of the heater should be considered.



Determination of Base Heating Requirements

If the composition, temperature, and pressure of the gas is known, the heat or enthalpy of the gas can be determined from an enthalpy diagram for natural gas. The amount of heat required to heat the gas can be determined so that the temperature of the gas on the outlet of the setting will be above 32F where freezing of earth surrounding outlet piping is encountered, or the required minimum temperature where internal regulator freezing is encountered.

1. Internal Freezing of Regulators. When internal freezing is involved, experience has shown that it is only necessary to provide sufficient heat to the gas to heat approximately 10 per cent of the maximum regulator capacity to a temperature slightly above the dew point of the gas to prevent liquid water from falling out which might cause freezing or hydrate formation. At flow rates greater than approximately 10 per cent of the maximum

regulator capacity, internal freezing is generally not encountered.

2. Freezing of Earth Surrounding Outlet Piping. The following example illustrates how the base heating requirements for a regulator heater can be determined.

Assume the following:

Flow Rate	20,000 Mcf/day
Flowing Gas Inlet Temperature	67F
Inlet Pressure	1200 psig
Outlet Pressure	350 psig
Dew Point	30F

With reference to the *Enthalpy Diagram*, the inter-section of the 67F line and the 1200 psig curve indicates an initial enthalpy or heat content of 3975 Btu per Mcf. To find the outlet temperature, the intersection of the 350 psig curve with the constant enthalpy line from the intersection of 67F and 1200 psig gives a temperature of 7.5F.

To prevent freezing of earth surrounding the outlet piping, the outlet gas temperature should be approximately 35F. The intersection of the 35F line with the 350 psig indicates an enthalpy of 4700 Btu per Mcf.

Therefore, the heat required to be added to the flowing gas would be:

Heat required = Btu difference × flow per day in Mcf
= 4700-3975 × 20,000
= 14,500,000 Btu per day OR 604,200 Btu per hr.

The temperature to which the inlet gas must be raised can also be determined by the intersection of the 1200 psig curve and the constant enthalpy line at 4700 Btu per Mcf indicating a temperature of 86F.

In using the change in enthalpy diagram, it is assumed that true throttling or Joule-Thompson expansion occurs at the reducing valve and the expansion takes place at constant enthalpy.

How To Size Meters For Domestic and Small Commercial Loads

Class I Meters

Meters in this class include those meters whose rated capacity at ½-in. water differential is approximately 150 to 225 cu ft per hour. They are generally used where domestic consumption consists of a gas range, storage type water heater, refrigerator, one or two space heaters, and for small heating requirements.

Class II Meters

Meters in this class include those meters whose rated capacity at ½-in. water differential is approximately 225 to 375 cu ft per hour. They are generally used where domestic consumption consists of a gas range, storage type water heater, refrigerator, and central house heating.

Larger Meters

Selection of the proper size meter to measure larger loads should be based upon an estimate of the total probable demands. The Table of Maximum Appliance Consumption is of help at arriving at this estimate. The table should be revised for each locality to include kinds and types of appliances generally used. Where automatic equipment is used, 100 per cent of the ratings should be used in estimating, and for all other appliances, a 70 per cent factor should be used.

Table of Maximum Appliance Consumption

Appliance	Btu's per hour
Domestic ranges	
Top burners	9–10,000
Giant burners	12,000
Ovens	16–18,000
Refrigerators	5,000
Water heaters	
Small	20,000
Medium	30–35,000
Large	55,000
Space heaters	
Per single candle	2,000
Per double candle	4,000
Incinerators	
Constant burning type	2,000
2 Bushel	15,000
4 Bushel (Commercial)	25,000
Laundry dryers	
Rotary type	20,000
Cabinet type	35,000
Circulating heaters	Use rated input
Central heating plants	
Gas designed	Use rated input
Conversion	Use calculated input

NOTE: This table furnishes the ratings of most of the appliances that have been sold in the last few years. Where appliances carry badged ratings, such ratings should be used. For older appliances, best estimate of gas requirements will be sufficiently close for this purpose.

Estimating Demand Per Hour

Estimated maximum demand per hour can be determined as follows:

$$\text{Maximum Demand (cu ft per hr)} = \frac{.70\,A + 1.00\,B}{C}$$

Where:

A = Btu rating per hour of non-automatic appliances
B = Btu rating per hour of all automatic appliances
C = Btu content of gas being distributed at meter outlet pressure.

Following is an example of the application of the table in arriving at an estimate of demand per hour, assuming 1000 Btu per cu ft natural gas:

Appliance	Rating Btu per hour	Total demand Btu per hour
Range (4 burner)	62,500	
Space heater	20,000	
Incinerator	15,000	
	97,500 at 70%	68,250
Instantaneous		
Water heater	150,000	
Hot water boiler	180,000	
	330,000 at 100%	330,000
		398,250

The Total demand in cu ft per hour is $\frac{398{,}250}{1000}$ or 398 cu ft per hour.

Periodic Check of Meter Sizes in Use

During winter months, route books should be reviewed periodically for meter size. When Class I meters exceed 50 Mcf and Class II meters exceed 100 Mcf for any reading period, they should be investigated for conclusive evidence of improper size.

Limitation: If reading period exceeds 1100 degree days, add 10 per cent to base (50 Mcf for Class I, 100 Mcf for Class II) for each 100 degree days.

High Pressure Measurement With PD Meters

Gas meters always measure the gas at line pressure. It is not always practicable to reduce the pressure and measure the gas at low pressure. In many instances it would be necessary to compress the gas again to transmit it to the point of consumption.

Meters for high pressure service have the same measuring mechanism as those employed for low pressure. The only difference is in the strength of the case.

If the line pressure does not remain constant, it is necessary to equip the meter with a recording volume and pressure gage in order to arrive at the correct base or selling pressure. The correct volume is computed from the gage chart and a pressure table.

If the line pressure remains constant, a pressure and volume gage is not necessary. The correct pressure factor may be taken from the table and applied directly to the meter reading.

The generally accepted average atmospheric pressure is 14.4 psi. Gage pressure is the difference between the absolute pressure and the atmospheric pressure, viz., the absolute pressure equals the atmospheric pressure plus gage pressure. Absolute pressure must be used in all gas calculations involving the gas laws.

The method of converting volume measured at high pressure to volume at a base or selling pressure is as follows:

$$Q = q \times K_{pb}$$

Where:

Q = quantity in cu ft at base pressure
q = cu ft registered by meter, index reading
K_{pb} = pressure base factor read from table below

Example:

Given: Meter index pressure = 215,512
Atmospheric pressure = 14.4 psi
Base pressure = 4 oz
Gage pressure = 45 psi

Then: in the table under "Base pressure 4 oz" read the constant for 45 psig, which is 4.005.

The volume measured at sales pressure then:

$Q = 4.005 \times 215{,}512$
$= 873{,}901$ cu ft

If the pressure varies, it is necessary to employ a recording volume and pressure gage. An average pressure for the volume measured is calculated from the gage chart. This average pressure is then interpolated in table of pressure factors and the calculations from this point are identical to those employed for a constant pressure.

Pressure Factors for High Pressure Measurement

Gauge pressure pounds	Base pressure, pounds absolute 14.65 (4 oz.)	14.9 (8 oz.)	15.025 (10 oz.)	16.4 (2 lb.)	Gauge pressure pounds	Base pressure, pounds absolute 14.65 (4 oz.)	14.9 (8 oz.)	15.025 (10 oz.)	16.4 (2 lb.)
0	0.983	0.966	0.958	0.878	38	3.577	3.517	3.488	3.195
1	1.051	1.034	1.025	0.939	39	3.645	3.584	3.554	3.256
2	1.119	1.101	1.092	1.000	40	3.713	3.651	3.621	3.317
3	1.188	1.168	1.158	1.061	41	3.782	3.718	3.687	3.378
4	1.256	1.235	1.225	1.122	42	3.849	3.785	3.754	3.439
5	1.324	1.302	1.291	1.183	43	3.918	3.852	3.820	3.500
6	1.392	1.369	1.358	1.244	44	3.986	3.919	3.887	3.561
7	1.461	1.436	1.424	1.305	45	4.055	3.987	3.953	3.622
8	1.529	1.503	1.491	1.366	46	4.123	4.054	4.020	3.683
9	1.597	1.570	1.557	1.427	47	4.191	4.121	4.087	3.744
10	1.666	1.638	1.624	1.488	48	4.259	4.188	4.153	3.805
11	1.734	1.705	1.691	1.549	49	4.328	4.255	4.220	3.866
12	1.802	1.772	1.757	1.610	50	4.396	4.322	4.286	3.927
13	1.870	1.839	1.824	1.671	51	4.464	4.389	4.353	3.988
14	1.939	1.906	1.890	1.732	52	4.352	4.456	4.419	4.049
15	2.007	1.973	1.957	1.793	53	4.601	4.523	4.486	4.110
16	2.075	2.040	2.023	1.854	54	4.669	4.591	4.552	4.171
17	2.143	2.107	2.090	1.915	55	4.737	4.658	4.619	4.232
18	2.212	2.174	2.156	1.976	56	4.805	4.725	4.686	4.293
19	2.280	2.242	2.223	2.037	57	4.874	4.792	4.752	4.354
20	2.348	2.309	2.290	2.098	58	4.942	4.859	4.819	4.415
21	2.116	2.376	2.356	2.159	59	5.010	4.926	4.885	4.476
22	2.485	2.443	2.423	2.220	60	5.078	4.993	4.952	4.537
23	2.553	2.510	2.489	2.280	61	5.147	5.060	5.018	4.598
24	2.621	2.577	2.556	2.341	62	5.215	5.128	5.085	4.659
25	2.689	2.644	2.622	2.402	63	5.283	5.195	5.151	4.720
26	2.758	2.711	2.689	2.463	64	5.352	5.262	5.218	4.780
27	2.826	2.779	2.755	2.524	65	5.420	5.329	5.285	4.841
28	2.894	2.846	2.822	2.585	66	5.488	5.396	5.351	4.902
29	2.962	2.913	2.889	2.645	67	5.556	5.463	5.418	4.963
30	3.031	2.980	2.955	2.707	68	5.625	5.530	5.484	5.024
31	3.099	3.047	3.022	2.768	69	5.693	5.597	5.551	5.085
32	3.167	3.114	3.088	2.829	70	5.761	5.664	5.617	5.146
33	3.235	3.181	3.155	2.890	71	5.829	5.732	5.684	5.207
34	3.304	3.248	3.221	2.951	72	5.898	5.799	5.750	5.268
35	3.372	3.315	3.288	3.012	73	5.966	5.866	5.817	5.329
36	3.440	3.383	3.354	3.073	74	6.034	5.933	5.884	5.390
37	3.509	3.450	3.421	3.134	75	6.102	6.000	5.950	5.451

Proof Testing Gas Meters For Accuracy

To arrive at accurate results in proof-testing gas meters necessitates close attention to a great many details. Merely connecting the meter to a prover and passing a small quantity of air or gas through, without strict regard to the following rules, will result in an approximation only and is not a correct proof test.

To proof test a meter accurately the prover must be mathematically correct, perfectly level, duly conterpoised and adjusted so as to give uniform pressure from top to bottom during the movement of the bell in the tank. Provers are commonly adjusted to throw a pressure of one and one-half inches water column. The liquid in the prover, the air or gas in the bell and also the meter to be proof tested must all be uniform in temperature with the air of the room in which the tests are to be made and all these temperatures must be kept uniform during the entire test.

The meter or meters to be proof tested should be brought to the proving room at least five hours or if possible for a longer period before making tests, thereby giving them an opportunity to become adjusted to room temperature. When these conditions have been met, the test may proceed.

Percentage of Error Table

	2 cubic feet passed by meter		5 cubic feet passed by meter		10 cubic feet passed by meter		20 cubic feet passed by meter	
	Prover	Error	Prover	Error	Prover	Error	Prover	Error
Fast	1.80	+11.11	4.50	+11.11	9.00	+11.11	18.00	+11.11
	1.81	+10.50	4.52	+10.62	9.05	+10.50	18.10	+10.50
	1.82	+ 9.89	4.55	+ 9.89	9.10	+ 9.89	18.20	+ 9.89
	1.83	+ 9.29	4.58	+ 9.17	9.15	+ 9.29	18.30	+ 9.29
	1.84	+ 8.70	4.60	+ 8.70	9.20	+ 8.70	18.40	+ 8.70
	1.85	+ 8.11	4.62	+ 8.20	9.25	+ 8.11	18.50	+ 8.11
	1.86	+ 7.53	4.65	+ 7.53	9.30	+ 7.53	18.60	+ 7.53
	1.87	+ 6.95	4.68	+ 6.84	9.35	+ 6.95	18.70	+ 6.95
	1.88	+ 6.38	4.70	+ 6.38	9.40	+ 6.38	18.80	+ 6.38
	1.89	+ 5.82	4.72	+ 5.93	9.45	+ 5.82	18.90	+ 5.82
	1.90	+ 5.26	4.75	+ 5.26	9.50	+ 5.26	19.00	+ 5.26
	1.91	+ 4.71	4.78	+ 4.60	9.55	+ 4.71	19.10	+ 4.71
	1.92	+ 4.17	4.80	+ 4.17	9.60	+ 4.17	19.20	+ 4.17
	1.93	+ 3.63	4.82	+ 3.73	9.65	+ 3.63	19.30	+ 3.63
	1.94	+ 3.09	4.85	+ 3.09	9.70	+ 3.09	19.40	+ 3.09
	1.95	+ 2.56	4.88	+ 2.46	9.75	+ 2.56	19.50	+ 2.56
	1.96	+ 2.04	4.90	+ 2.04	9.80	+ 2.04	19.60	+ 2.04
	1.97	+ 1.52	4.92	+ 1.63	9.85	+ 1.52	19.70	+ 1.52
	1.98	+ 1.01	4.95	+ 1.01	9.90	+ 1.01	19.80	+ 1.01
	1.99	+ 0.50	4.98	+ 0.40	9.95	+ 0.50	19.90	+ 0.50
Correct	2.00	0.00	5.00	0.00	10.00	0.00	20.00	0.00
Slow	2.01	−0.50	5.02	−0.40	10.05	−0.50	20.10	−0.50
	2.02	−0.99	5.05	−0.99	10.10	−0.99	20.20	−0.99
	2.03	−1.48	5.08	−1.57	10.15	−1.48	20.30	−1.48
	2.04	−1.96	5.10	−1.96	10.20	−1.96	20.40	−1.96
	2.05	−2.44	5.12	−2.34	10.15	−2.44	20.50	−2.44
	2.06	−2.91	5.15	−2.91	10.30	−2.91	20.60	−2.91
	2.07	−3.38	5.18	−3.47	10.35	−3.38	20.70	−3.38
	2.08	−3.85	5.20	−3.85	10.40	−3.85	20.80	−3.85
	2.09	−4.31	5.22	−4.21	10.45	−4.31	20.90	−4.31
	2.10	−4.76	5.25	−4.76	10.50	−4.76	21.00	−4.76
	2.11	−5.21	5.28	−5.30	10.55	−5.21	21.10	−5.21
	2.12	−5.66	5.30	−5.66	10.60	−5.66	21.20	−5.66
	2.13	−6.10	5.32	−6.02	10.65	−6.10	21.30	−6.10
	2.14	−6.54	5.35	−6.54	10.70	−6.54	21.40	−6.54
	2.15	−6.98	5.38	−7.06	10.75	−6.98	21.50	−6.98
	2.16	−7.41	5.40	−7.41	10.80	−7.41	21.60	−7.41
	2.17	−7.83	5.42	−7.75	10.85	−7.83	21.70	−7.83
	2.18	−8.26	5.45	−8.26	10.90	−8.26	21.80	−8.26
	2.19	−8.68	5.48	−8.76	10.95	−8.68	21.90	−8.68
	2.20	−9.09	5.50	−9.09	11.00	−9.09	22.00	−9.09

The inlet of the meter is connected to the prover hose by means of a suitable connection. The connections and meter are then tested for leaks by opening the outlet valve on the prover connections, placing the palm of the hand over the meter outlet, and then closing the valve. If the siphon gauge shows a drop in pressure, it is an indication of a leak in the connection or in the meter. The leak can be located by means of soapsuds.

Attach the proper check cap on the meter outlet and pass enough air from the prover through the meter to bring the test hand, while on the up run, directly over a division or mark on the proving circle.

Fill the prover bell and carefully adjust the zero scale reading by means of the prover slide valve. Open the valve on the connection and pass a sufficient volume from the prover through the meter to cause the test hand to make one full revolution. Exercise care to insure that the test hand is stopped exactly over the mark from which it started at the beginning of the test. The reading on the prover scale is noted and from these data the proof is determined. If the meter is to be proof tested at the open rate, the procedure is the same as with the check rate test with the exception that the meter outlet is unrestricted. The maximum rate at which the prover delivers air through the hose and connections to the meter at the open-rate test depends upon the capacity of the meter, pressure in the prover, and size of connections from the interior of the prover to the meter.

Differential Test

The differential test of meters at a definite check rate is the supplementary test which is used as a final check to determine the absence of avoidable internal friction or binds in meters before final proof. For this purpose the differential, which is the difference in pressure between the inlet and outlet of the meter, is indicated in inches of water on a sensitive draft gauge.

At a very low rate of flow the differential is produced primarily by internal friction. In a properly assembled meter this internal friction depends upon the flexibility of the diaphragms, the relative tightness of the stuffing boxes, and to a certain extent, upon the clearance between the moving parts. In some cases where heavier diaphragms or tighter packing of the stuffing boxes are specified, a slightly higher differential will result. Consequently, for any particular size of meter, the differential limits will depend upon the specifications.

Any increase in differential resulting from binds, excessive friction in the stuffing boxes, or stiff diaphragm leather should be eliminated before final proof. This precaution is of basic importance because if internal friction is reduced by wear after a meter is placed in service, the proof may be affected.

At low rates of flow, the differential between meter inlet and outlet pressures may be about 0.10 inches of water.

American Meter Company, Inc.

Design of Large Volume Gas Measurement Facilities

THE measurement of the volume of gas delivered to large volume purchasers such as to secondary transmission systems, cities (via city gate stations) power plants and large industrial plants, is usually accomplished by using one of the following installations:

1. Positive displacement meters of large capacity, operating singly or in multiple (two or more in parallel).
2. Differential type orifice flow meters with simplex flow recorders, with or without automatic trip-over devices. By "simplex flow recorder" is meant a single range flow recorder (meters employing simplex flow recorders are herein referred to as "simplex orifice meters").
3. Differential type orifice flow meter with duplex flow recorder in one orifice run, or in the first of several orifice runs with trip-over devices (using simplex flow recorders in the balance of the orifice runs). By "duplex flow recorder" is meant a dual range flow recorder which usually consists of two single range recorders acting together—one for low range operation, and one for high range operation (meters employing duplex flow recorders are herein referred to as "duplex orifice meters").
4. Positive displacement meters replacing the differential type orifice flow meter in the first run of a multiple orifice run installation, with trip-over devices.

The type of metering equipment to be installed depends upon requirements to be met, particularly the requirements concerning maximum and minimum flow.

Positive Displacement Meters are used singly or in parallel:

1. Where minimum volume flows approach zero.
2. Where maximum volume flows are comparatively small.

Simplex Differential Type Orifice Flow Meters are used singly or in parallel:

1. Where minimum volume flows to be measured are not too critical.
2. Where maximum volume flows are comparatively large.

Duplex Differential Type Orifice Flow Meters are used either alone or in parallel with simplex type meters:

1. Where minimum volume flows to measured are more critical than can be handled on a simplex meter.
2. Where maximum volume flows are comparatively large.

Positive Displacement Meters are used in parallel with simplex differential type meters:

1. Where minimum volume flows approach zero.
2. Where maximum volume flows are comparatively large.

A 100-in. simplex flow recorder is accurate over a range from approximately 6 to 96-in., and has a flow ratio of approximately 4 to 1.

A 20-in. and a 100-in. flow recorder used in a duplex setting has a range from approximately 2 to 96-in. and has a flow ratio of approximately 7 to 1.

A 10-in. and a 100-in. flow recorder used in duplex setting has a range from approximately 1 to 96-in. or a flow ratio of approximately 10 to 1.

The flow ratios shown above will apply only to the first run in a multiple meter run installation inasmuch as allowances for proper operation of trip-over devices results in lower flow ratios for the succeeding runs.

A positive displacement meter has a flow range from zero to the full capacity of the meter. For purposes of comparison with an orifice flow meter the positive displacement meter can be considered as a meter having a range from 0 to 96 inches, and an infinite flow ratio.

For each particular installation the engineer must select the most economical and efficient measurement equipment for the service intended. This involves the determination of minimum and maximum flows to be measured, the study of growth requirements, operating pressures, and other pertinent facts.

Orifice Flow Meters

The basic formula for measurement of gas flow by an orifice meter is:

$$Q_h = C' \sqrt{h_w P_f} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Where:

Q_h = rate of flow at base conditions in cu ft per hr
C' = orifice flow constant
h_w = orifice pressure differential in inches of water
P_f = absolute static pressure in psi

In the above equation

$$C' = F_b \times F_r \times Y \times F_{pb} \times F_{tb} \times F_{tf} \times F_g \times F_{pv} \times F_m \quad . \quad (2)$$

Where:

F_b = basic orifice flow factor
F_r = Reynold's number factor
Y = expansion factor
F_{pb} = pressure base factor
F_{tb} = temperature base factor
F_{tf} = flowing temperature factor
F_g = specific gravity factor
F_{pv} = supercompressibility factor
F_m = manometer factor*

For purposes of *preliminary* design the factors F_r, Y, F_{pv} and F_m can be neglected, and the remaining factors F_{pb}, F_{tb}, F_{tf} and F_g become constants for the particular design conditions.

Letting $$C'' = F_{pb} \times F_{tb} \times F_{tf} \times F_g \quad . \quad . \quad . \quad . \quad (3)$$

the flow formula for *preliminary design purposes only*, becomes $$Q_h = F_b \times C'' \sqrt{h_w P_f} \quad . \quad . \quad . \quad . \quad (4)$$

In design, where several meter runs are to be operated in parallel, the total maximum flow can be represented by the formula:

$$Q_H = F_B \times C'' \sqrt{h_w P_f} \quad . \quad . \quad . \quad . \quad (5)$$

Where:

$$F_B = F_{b_1} + F_{b_2} + F_{b_3} \ldots \text{etc.}$$

and F_{b_1}, F_{b_2}, and F_{b_3} represent the basic orifice factors of each individual run in the multiple installation.

In meter station design, it is common practice to use orifice plates with standard bores which vary in multiples of ⅛-in. and ¼-in. according to size of meter run involved. Since the basic orifice factor is established by these standard orifices it is advisable to provide leaway in design calculations so that the final design will handle the total flow requirements. Therefore, in preliminary design calculations it is recommended that the maximum flow requirements be increased 10 per cent and equation (5) can be revised and rewritten as follows:

$$C'' = \frac{1.1 \quad Q_H}{F_B \sqrt{h_w p_f}} \quad . \quad . \quad . \quad . \quad . \quad (6)$$

While it might be felt that the 10 per cent increase in the maximum flow requirements will result in a larger size installation than necessary, the practice of selecting orifices

*As it appears in AGA Gas Measurement Committee Report No. 3.

having a basic orifice factor equal to or slightly less than the required basic orifice factor (which has been calculated) results in a system having a capacity close to the specified requirements.

It is common practice when several meter runs are operated in parallel, for the installation to be provided with a mechanical means of increasing or decreasing the number of meter runs in service. This is done in order to adapt the installation to varying flow requirements. Thus, as the flow is increased from minimum to maximum, one or more meter runs will be successively added to the initial run. Likewise, as the flow rate decreases from maximum to minimum these additional runs are cut out of service until only the initial run remains in operation. The adding or subtracting of each successive meter run is performed by a trip valve which operates automatically to add or subtract a meter run at preset maximum and minimum flow ratio. In order to provide proper sequence of operation, these maximum and minimum flows must be established for each individual meter run, for it is essential that the trip points selected permit **only** the designated meter run to operate.

In developing "work sheets" for the design of a multiple run 100 inch simplex orifice meter installations, the following assumptions apply to all designs:

(1) The minimum accurate recordable flow differential for a 100-in. simplex flow meter is 6-in. of water.

(2) The upper trip point in **all** meter runs in a multiple run installation is to be set at a differential of 96-in.

(3) The lower trip point in a multiple run installation is to be set at a differential of 6.5-in. in Run No. 1, 8.0-in. in Run No. 2, and 9.5-in. in Run No. 3.

(4) A flow causing a differential of 96-in. in one meter run will cause a differential of 7.5-in. in two parallel runs; a flow causing a differential of 96-in. in two parallel meter runs will cause a differential of 9.0-in. in three parallel meter runs; and a flow causing a differential of 96-in. in three parallel meter runs will cause a differential of 10.5-in. in four parallel meter runs, etc.

(5) The ratio of maximum to minimum flow in each meter run is the square root of the maximum differential (96-in.) divided by the square root of the minimum differential (as described in 4 above).

Assigning a value of 1.0 (unity) to the minimum flow for a single 100-in. simplex meter run (6.0-in. differential), and utilizing the previously stated assumptions, the following capacity calculations have been made for installations having multiple runs with trip-over valves:

Type of installation	Differential (In. of water)	*Flow capacity (Units)	Calculation
One run only	6.0	1.0	
	96.0	4.0	$\sqrt{\frac{96.0}{6.0}} \times 1.0 = 4.0$
Two runs in parallel	7.5	4.0	Same flow as above divided to two runs.
	96.0	14.3	$\sqrt{\frac{96.0}{7.5}} \times 4.0 = 14.3$
Three runs in parallel	9.0	14.3	Same flow as above divided into three runs.
	96.0	46.7	$\sqrt{\frac{96.0}{9.0}} \times 14.3 = 46.7$
Four runs in parellel	10.5	46.7	Same flow as above divided into four runs.
	96.0	141.3	$\sqrt{\frac{96.0}{10.5}} \times 46.7 = 141.3$

*Since the minimum flow of the first run was taken as unity, the maximum flow **capacity** calculated for a multiple run installation is also the maximum flow **ratio** for such an installation.

The maximum flow in each individual run can be readily determined by subtracting from the total capacity of the multiple installation, the 96-in. flow capacity unit values of all the runs except the last. This gives the following:

Run No.	Total capacity All runs	Total capacity All runs except last run	Capacity of last run
4	141.3	46.7	94.6
3	46.7	14.3	32.4
2	14.3	4.0	10.3
1	4.0	—	4.0

The maximum flow ratios and trip points calculated by the above method, are listed in Table No. 1. This table shows flow ratio data and trip point data for both "simplex" and "duplex" orifice flow meter installations having a maximum of four (4) parallel runs with a maximum total basic orifice factor (F_B) of approximately 40,000.

Table No. 1 also shows "K values" for each type of installation. These "K values" are constants, which, when multiplied by the maximum flow for which the entire installation is to be designed, gives the maximum flow requirements for each individual run to be used in the installation. In design calculations, the "K values" are used as multipliers of the total basic orifice flow factor for the entire installation (F_B) to obtain the basic orifice flow factor of each individual run (F_{b_1}, F_{b_2}, etc.).

Calculations and procedures discussed in the preceding paragraphs cover "simplex" meter installations only. The development of capacities and ratios for installations having a duplex meter in the first run is basically the same as for installations having a simplex meter in the first run. Table I shows design data for both "simplex" and "duplex" installations.

Positive Displacement Meters

The design of installations that use positive displacement meters **only,** operating singly or in parallel, presents no un-

TABLE 1.

Maximum flow ratio			Number of meter runs	Trip point (Inches water)		K Value Meter run			
Simplex	Duplex type A	Duplex type B		Min.	Max.	1	2	3	4
4.0									
	7.0		1	6.5	96.0	1.000	—	—	—
		10.0							
14.3									
	25.0		2	8.0	96.0	0.280	0.720	—	—
		35.8							
46.7									
	81.8		3	9.5	96.0	0.085	0.221	0.694	—
		116.6							
141.3				—	—	0.028	0.073	0.229	0.670
	247.3		4						
		353.3							

The systems listed above as "Simplex" have 100-in. differential type flowmeters in all runs.

The systems listed as "Duplex-Type A" have 20-in. and 100-in. meters in the first run, and 100-in. meters in all additional meter runs.

The system listed as "Duplex-Type B" have 10-in. and 100-in. meters in the first run, and 100-in. meters in all additional meter runs.

Maximum flow ratios are based on constant meter run pressures at both high and low flow rates. If meter run pressure is not controlled, these factors must be changed by ratio of square roots of absolute pressures at low and high flow conditions.

usual problems. When a positive displacement meter is used in the first run of a multiple run installation employing differential type meters, it has been found desirable to establish a definite procedure for the design of the installation. The recommended procedure is given in Section III, Part 3 of the "work sheets", and covers the determination of an economical installation having its first run capacity within the limits of an available standard size positive displacement meter.

Work Sheets

The following "work sheets" have been developed based on the design theories previously expressed. The "work sheets" make no attempt to explain each step of the calculation, it being expected that engineers using these "work sheets" will be familiar with basic flow meter system requirements and calculations, and the necessary data books will be available for their use.

CALCULATED BY A.B.C.
DATE 11-15-56
CHECKED BY D.E.F.

GAS FLOW METER
CALCULATIONS
WORK SHEET NO 1 OF 4

I DESIGN CONDITIONS:

Maximum quantity of gas to be metered (Q_H)	200,000 SCFH
Minimum quantity of gas to be metered (Q_L)	2,000 SCFH
Specific gravity of gas, relative to air (SG)	0.60
Flowing pressure (P)	100 PSIG
Flowing temperature (T)	65 °F
Pressure base (contract)	14.4 PSIA
Temperature base (contract)	60 °F

II TOTAL BASIC ORIFICE FLOW FACTOR (F_B) CALCULATIONS:

Determine total basic orifice factor as follows:

$$F_B = \frac{1.1\ Q_H}{C'\sqrt{h_w P_f}}$$

F_B = total basic orifice flow factor = F_{b_1} F_{b_2} F_{b_3} etc.
(F_{b_1}, F_{b_2}, etc. are basic orifice coefficients for individual meter runs)
Q_H = maximum quantity of gas to be metered (from design conditions)

F_{pb} = pressure base factor (14.4 PSIA = 1)**	1.0
F_{tb} = temperature base factor (60°F = 1)	1.0
F_{tf} = flowing temperature factor (60°F = 1)	.9952
F_g = specific gravity factor (SG 0.60 = 1.291)	1.291
$C' = F_{pb} \times F_{tb} \times F_{tf} \times F_g$ (for preliminary calculations) =	1.285

h_w = 96 in., maximum
$P_f = P + 15 =$ 115

$$\frac{h_w P_f}{\sqrt{h_w P_f}} = \frac{11,040}{105}$$

$$F_B = \frac{1.1\ Q_H}{C'\sqrt{h_w P_f}} = \frac{1.1 \times (200,000)}{(1.285) \times (105)} = 1630.0$$

* F_B increased 10% for flexibility of design
** See tables in this handbook for conversion factors

CALCULATED BY A.B.C.
DATE 11-15-56
CHECKED BY D.E.F.

GAS FLOW METER
CALCULATIONS
WORK SHEET NO 2 OF 4

Column Number / Type of Installation	1 1 P D Run 1 Simplex Run	2 1 P D Run 2 Simplex Runs	3 1 P D Run 3 Simplex Runs
Equation For Required Capacity in P D Meter	= ¼ x Max. Flow / 14.3	= ½ x Max. Flow / 58.7	= ¾ x Max. Flow / 141.3
Required Capacity, SCFH	56,000	17,150	
Manufacturer	Not Manufactured	XYZ Meter Co.	
Model No.		20-A	
Rated Capacity at Flow Conditions		20,000 SCFH	

4) After considering economy, provision for future expansion, and general conditions affecting the installation, select from the preceding tables the metering system to be used. List below the system selected.

Number of runs 3

Meter(s) for initial (check) meter run (one)
- ☐ Simplex (100")
- ☐ Duplex Type A (20" and 100")
- ☑ Duplex Type B (10" and 100")
- ☐ Positive displacement

Basis of selection: Installation costs will be kept to a minimum if either a PD meter or a Duplex Type B meter is used in the first meter run.

CALCULATED BY A.B.C.
DATE 11-15-56
CHECKED BY D.E.F.

GAS FLOW METER
CALCULATIONS
WORK SHEET NO 3 OF 4

III SELECTION OF METERING SYSTEM

1) Calculate the maximum flow ratio for the proposed installation as follows:

Maximum Flow Ratio = Maximum quantity of gas to be metered / Minimum quantity of gas to be metered

$$= \frac{Q_H}{Q_L} = \frac{200,000}{2,000} = 100$$

2) For the above calculated flow ratio, select the total minimum number of meter runs required for each of the three types of installations listed on Table No. 1 and complete the following

	Type of Installation	Simplex	Duplex Type A	Duplex Type B
	Calculated Maximum Flow Ratio	100	100	100
	Tabulated Maximum Flow Ratio**	141.3	247.3	116.6
Meter Runs	Total - Minimum No. of Runs Req'd**	4	4	3
	Less - No. of Duplex Runs	0	1	1
	Equals - No. of Simplex Runs Req'd	4	3	2

**From Table 1.

3) If a positive displacement meter is required in the first run of a multiple run installation, the following tabulation should be used to determine the number of meter runs and size of meter required. Columns 1, 2, and 3 of the table should be successively calculated to determine the capacity (at flow conditions) of a standard size positive displacement meter for installation in the first run.

CALCULATED BY A.B.C.
DATE 11-15-56
CHECKED BY D.E.F.

GAS FLOW METER
CALCULATIONS
WORK SHEET NO 4 OF 4

IV. COMPLETION OF DESIGN:

Complete design on chart using data given on Table 1, and preceding calculations.

Meter Run		1 1	2 2	3 3	4 4
Total Orifice Factor F_B (from Sheet No. 1)		1630	1630	1630	
K Factor (from Table No. 1)		.085	.221	.649	
F_b theoretical (F_B x K Factor)		138.5	373.0	1057.9	
Type of Taps (Flange or pipe)		FT	FT	FT	
F_b actual - selected from handbook		162.11	402.10	1114.9	
ID of Meter Run, Inches		2.067	3.068	4.026	
Orifice Bore, Inches		.875	1.375	2.250	
Beta Ratio		.423	.449	.559	
Individual Run	Minimum Flow, SCFH	1980	12,800	39,500	
	Low Trip Point, Inches	6.5	8.0	—	
	Maximum Flow, SCFH	19,800	49,200	136,800	
	High Trip Point, Inches	96	96	—	
Cumulative	Minimum Flow, SCFH	1980	18,000	59,400	
	Maximum Flow, SCFH	19,800	69,000	205,800	

V. DESIGN COMMENTS: If a large future growth is probable with a corresponding increase in the minimum flow requirements, a 6.065-inch ID meter run with 2.375-inch orifice bore (Beta Ratio = 0.392) should be used in Run #3 in place of the 4.026 ID run shown.

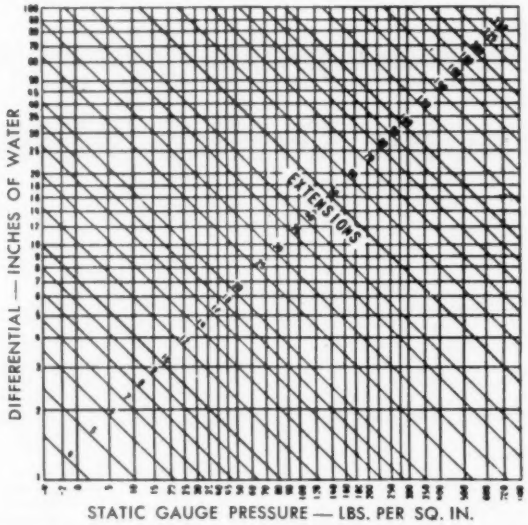
METHODS OF DETERMINING APPROXIMATE HOURLY FLOW THROUGH AN ORIFICE METER

(1) Locate differential on left margin.

(2) Trace to right to perpendicular line representing static gauge pressure on bottom scale.

(3) Read extension factor from diagonal lines.

(4) Hourly flow in cu ft = extension factor + orifice flow constants taken from tables No. XIV or XV.



Example: Assume an orifice meter with a 2 in. orifice in a 4 in. pipe run, having a differential of 40 in. and a static pressure of 200 lbs, flange taps being used.

Then: Extension = 95
Orifice flow constant = 1070
Hourly flow = 95 × 1070 = 102,000 cu ft.

APPROXIMATE HOURLY ORIFICE FLOW CONSTANTS — FLANGE TAPS

Based on .65 specific gravity gas at average atmospheric pressure and temperature. TABLE XIV

Orifice diameter inches	Pipe size 2″Std. (2.067)	3″Std. (3.068)	4″Std. (4.026)	6″Std. (6.065)	8″Std. (8.071)	10″Std. (10.136)	12″Std. (12.090)
.25	16	16	16				
.375	36	36	36				
.50	64	64	64	64			
.625	101	100	99	99			
.75	146	144	143	143			
.875	201	197	196	195	195		
1.00	267	258	256	255	254		
1.125	345	329	325	323	322	322	
1.25	438	409	403	399	398	397	397
1.375	550	499	489	484	482	481	481
1.50	688	600	585	577	574	573	572
1.625		714	690	678	675	673	672
1.75		842	805	788	783	781	780
1.875		986	931	906	900	898	896
2.00		1150	1070	1030	1030	1020	1020
2.125		1340	1220	1170	1160	1160	1150
2.25		1550	1380	1320	1300	1300	1290
2.375			1560	1470	1450	1540	1440
2.50			1760	1630	1610	1600	1600
2.625			1980	1810	1780	1770	1760
2.75			2220	2000	1960	1940	1940
2.875			2480	2190	2140	2130	2120
3.00			2790	2400	2340	2320	2310
3.125				2620	2540	2520	2510
3.25				2860	2760	2730	2710
3.375				3100	2980	2940	2930
3.50				3370	3220	3170	3150
3.625				3650	3460	3410	3390
3.75				3950	3720	3650	3630
3.875				4270	3990	3910	3880
4.00				4600	4270	4170	4130
4.25				5350	4860	4730	4680
4.50				6220	5520	5330	5260
4.75					6230	5970	5880
5.00					7020	6660	6540
5.25					7880	7400	7240
5.50					8820	8190	7980
5.75					9870	9040	8760
6.00					11000	9960	9600
6.25	Note. The above Flow Constants					10900	10500
6.50	are only approximate values and					12000	11400
6.75	should not be used in Commercial					13100	12400
7.00	Gas Measurement Computations.					14400	13500
7.25						15700	14600
7.50						17200	15800
7.75							17000
8.00							18400
8.25							19800

APPROXIMATE HOURLY ORIFICE FLOW CONSTANTS — PIPE TAPS

Based on .65 specific gravity gas at average atmospheric pressure and temperature. TABLE XV

Orifice diameter inches	Pipe sizes 2″Std. (2.067)	3″Std. (3.068)	4″Std. (4.026)	6″Std. (6.065)	8″Std. (8.071)	10″Std. (10.136)	12″Std (12.090)
.25	16	16	16				
.375	37	36	36				
.50	67	65	65	64			
.625	107	103	101	100			
.75	159	150	147	145			
.875	225	207	202	198	197		
1.00	309	276	266	259	257		
1.125	416	357	341	330	326	325	
1.25	556	453	428	410	404	402	400
1.375	741	566	526	499	491	487	485
1.50		698	637	598	586	581	578
1.625		854	764	708	691	683	679
1.75		1040	906	829	805	795	789
1.875		1260	1070	961	929	915	908
2.00		1530	1250	1110	1060	1050	1040
2.125		1860	1460	1260	1210	1180	1170
2.25			1690	1430	1360	1330	1320
2.375			1960	1620	1530	1490	1470
2.50			2270	1820	1710	1660	1640
2.625			2630	2040	1900	1840	1811
2.75			3050	2270	2100	2030	2000
2.875				2530	2320	2230	2190
3.00				2810	2550	2440	2390
3.125				3110	2790	2670	2610
3.25				3440	3050	2900	2830
3.375				3800	3330	3150	3070
3.50				4190	3620	3410	3320
3.625				4620	3930	3690	3570
3.75				5090	4260	3980	3840
3.875				5610	4620	4280	4130
4.00				6190	4990	4600	4420
4.25					5820	5280	5050
4.50					6760	6030	5730
4.75					7840	6860	6470
5.00					9070	7780	7280
5.25					10500	8800	8150
5.50					12200	9920	9100
5.75						11200	10100
6.00						12600	11200
6.25	Note: The above Flow Constants					14100	12500
6.50	are only approximate values and					15900	13800
6.75	should not be used in Commercial					17800	15200
7.00	Gas Measurement Computations.					20000	16800
7.25							18500
7.50							20400
7.75							22500
8.00							24800
8.25							27400

From Report No. 2, Practical Methods Committee, Appalachian Gas Measurement Short Course, School of Mines, West Virginia University, 1940.

How To Compute Flow of Gas Through Orifice Meters

Tables and data presented here are based on the Gas Measurement Committee Report No. 3, American Gas Association, and are the same except that tables are calculated using a base pressure of 14.4 psia. — Editor.

General Equation

In the measurement of most gases, and especially natural gas, it is almost the universal practice (in the United States) to express the flow in cubic feet per hour referred to some specified reference or base condition of pressure and temperature. For the calculation of the quantity of gas the committee recommends the continued use of the formula:

$$Q_h = C' \sqrt{h_w p_f} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

in which

Q_h = Quantity rate of flow at base conditions, ft^3/hr
C' = Orifice flow constant
h_w = Differential pressure in inches of water
p_f = Absolute static pressure in psi

Orifice Flow Constant

The orifice flow constant, C′, may be defined as the rate of flow, in cubic feet per hour, at base conditions, when the extension, $\sqrt{h_w p_f}$ equals one. It was formerly known as the "flow coefficient." It is here called "orifice flow constant." It is to be calculated by the following equation:

$$C' = F_b \times F_r \times Y \times F_{pb} \times F_{tb} \times F_{tf} \times F_g \times F_{pv} \quad (2)$$

in which

F_b = Basic orifice flow factor
F_r = Reynolds' number factor
Y = Expansion factor
F_{pb} = Pressure base factor
F_{tb} = Temperature base factor
F_{tf} = Flowing temperature factor
F_g = Specific gravity factor
F_{pv} = Supercompressibility factor

It will be noted that all of the factors used in calculating the orific flow constants are familiar except F_r, F_b, Y and F_{pv}.

The values of all the factors F_b, F_r, etc., are obtained from the tables. The following method is for a meter with flange taps. The method for a meter with pipe taps will be exactly the same, except that the tables for pipe taps will be used.

Basic Orifice Flow Factor

The basic orifice flow factor, F_b, is taken directly from Table 1, for the correct orifice and pipe size. For sizes not listed in this table, values of F_b may be calculated as follows:

The pipe diameter of the orifice sections should be within the limits specified in the table below. If the value of D_1 is outside of those limits the flow factors of Table 1 cannot be relied upon. Then the exact value of F_b should be calculated for the particular value of "β" based on the actual value of D_1.

Orifice to Pipe Diameter	Recommended Maximum Allowable Tolerance between Measured inside Diameter of the upstream section of the meter run, and the Published "Approximate Internal Diameter", which was used in Computing Basic Orifice Constants of this Report.	
Ratio "β"	Flange Taps	Pipe Taps
.10 to .25	5.0%	3.5%
.25 to .35	3.0%	2.0%
.35 to .45	2.0%	1.0%
.45 to .55	1.5%	0.6%
.55 to .65	1.0%	0.3%
.65 to .75	0.5%	0.2%

Calculation of F_b. Two simplified formulas, which have been developed for calculating Report No. 2 and No. 3 orifice coefficients are as follows:

$$F_b = F_1 \times F_d \times D_2^2$$

and

$$F_b = F_x \times F_d \times D_1^2$$

where:

F_b = Basic orifice coefficient
D_1 = Diameter of meter run in inches
D_2 = Diameter of orifice in inches
$\beta = \dfrac{D_2}{D_1}$
F_1 = 345.92 K_o for 4.026-in. line
F_x = 345.92 $K_o \beta^2$ for 4.026-in. line
F_d = factor for converting K_o for 4.026-in. line for various values of β to values of K_o for other line sizes.

The original or basic formula is:

$$F_b = 345.92\ K_o\ D_2^2$$

Procedure for using simplified formulas:

1. Obtain β: $\beta = \dfrac{D_2}{D_1}$
2. Obtain F_1: From F_1 tables (for type of meter connections) for corresponding value of β, interpolate
3. Obtain F_d: From F_d tables (for type of meter connections) for corresponding value of β, interpolate
4. Obtain D_2^2: Multiply orifice diameter by itself
5. Obtain F_b: Multiply these values: $F_1 \times F_d \times D_2^2$

EXAMPLE

6.065 by 2.0 Orifice Plate, Flange Taps.

$$\beta = \frac{2.0}{6.065} = .329761$$

$F_1 = 208.2752$ (Interpolated from F_1 tables)
$F_d = 1.000$ (Interpolated from F_d tables)
$D_2^2 = 2.0 \times 2.0 = 4.0$
$F_b = F_1 \times F_b \times D_2^2$
$= 208.2752 \times 1.000 \times 4.0 = 833.10$

Where it is desired to use the second equation to check calculations or for other reasons, the procedure which should be used is as follows:

EXAMPLE

1. Obtain β: $\beta = \frac{D_2}{D_1}$
2. Obtain F_x: From F_x tables (for type of meter connections) for corresponding value β, interpolate
3. Obtain F_d*: From F_d tables (for type of meter connections) for corresponding value of β, interpolate
4. Obtain D_1^2: Multiply pipe diameter by itself
5. Obtain F_b: Multiply these values — $F_x \times F_d \times D_1^2$.

EXAMPLE

6.065 by 2.0 Orifice Plate, Flange taps.

$$\beta = \frac{2.0}{6.065} = .329761$$

$F_x = 22.6485$, interpolated from F_x tables
$F_d = 1.000$, interpolated from F_d tables
$D_1^2 = 6.065 \times 6.065 = 36.784225$
$F_b = 22.6485 \times 1.000 \times 36.7842 = 833.11$

Note that the coefficients calculated for the same plate by these two simple formulas are practically the same as the one found in the tables, and serve as an excellent check on results.

Where β (ratio of orifice diameter to pipe diameter) is less than 0.100 or more than 0.750, no flow factors appear in the tables. Since volume calculation under such flow conditions is inaccurate, a Report No. 1 coefficient may be used, as results, to a varying degree, would only be a good indication of the rate of flow.

Reynolds' Number Factor

This factor, F_r, is obtained from the formula:

$$F_r = 1 + \frac{b}{\sqrt{h_w p_f}}$$

The values of b are given in Tables 5 and 5-A for standard size pipe and even size orifices. If the diameter of the orifice is not an even size in these tables, the proper b factor for determining F_r can be found in Tables 6 and 6-A.

Expansion Factor

The expansion factor, Y, is given in Table 7 and the factor to use depends on the tap location from which the static pressure is taken. Three tables of expansion factors are given for flange taps: Y_1 for upstream static pressure; Y_m for mean static pressure; and Y_2 for downstream static pressure. For pipe taps, two tables are provided: Y_1 for upstream static pressure and Y_2 for downstream static pressure.

Pressure Base Factor

The pressure base factor, F_{pb}, is taken from Table 8.

Temperature Base Factor

The temperature base factor, F_{tb}, is taken from Table 9.

Flowing Temperature Factor

The flowing temperature factor, F_{tf}, is taken from Table 10, and should be based on the actual flowing temperature of the gas.

Specific Gravity Factor

The specific gravity factor, F_g, is taken from Table 11, and should be based on the actual specific gravity of the gas as determined by test, and the portion of table nearest to this used, with linear interpolation if necessary.

Application and Examples

In the application of these factors, it will be noted that F_r, Y, F_{pb}, F_{tf}, F_g and F_{pv} are multipliers, and may be applied either to the base orifice flow factor, F_b, or to the calculated quantity rate of flow, as preferred.

EXAMPLE

Given:

D_1 = Line size = 8-in. nominal inside diameter = 8.071 in. actual inside diameter.
D_2 = orifice size = 1.000 in.
Meter equipped with flange taps, with static pressure from downstream tap.
T_f = Flowing temperature = 65F.
P_b = 4 oz above 14.4 psi (= 14.65 psia) = pressure base.
T_b = Temperature base = 50F = 510 absolute.
Specific gravity = .570.
Average differential head h_w = 50 in. water.
Average downstream static pressure, p_f = 40 psia.
Supercompressibility ratio (by test), N = 0.004.

Required:

The orifice flow constant and the quantity rate of flow for one hour at base conditions.

$$\beta = \frac{D_2}{D_1} = .1239$$

Published approximate inside diameter of pipe = 8.071.
Ratio actual inside diameter to approximate inside diameter = 1.000.
Per cent difference = 0.0 therefore tables can be used.
Average $\sqrt{h_w p_f} = 44.72$

$$\text{Average } \frac{h_w}{p_f} = 1.25$$

From Table 1 for 1-in. plate in 8-in. line:
$F_b = 204.97$
From Table 5 (8-in. line, 1-in. plate)
Where $\sqrt{40 \times 50} = 44.72$

$$F_r = 1 + \frac{.0680}{44.72}$$

$F_r = 1 + .0015$
$F_r = 1.0015$

From Table 7 (Y_2 for downstream static pressure)

at $\frac{h_w}{p_f} = 1.2$ and $\beta = .1$ and $.2$; $Y_2 = 1.0080$
at $\frac{h_w}{p_f} = 1.3$ and $\beta = .1$ and $.2$; $Y_2 = 1.0087$

Interpolating for

$\frac{h_w}{p_f} = 1.25$ and $\beta = .1239$; $Y_2 = 1.0084$

From Table 8

for 4 oz above 14.4 psia; $F_{pb} = .9829$

From Table 9

for $T_b = 50F$; $F_{tb} = .9808$

From Table 10

for $T_f = 65F$; $F_{tf} = .9952$

From Table 11

for Specific Gravity = .570; $F_g = 1.3245$

Then the orifice flow constant is:

$C' = 204.97 \times 1.0015 \times 1.0088 \times .9829 \times .9808 \times .9952 \times 1.3245 = 263.65$

and the rate of flow for 1 hour at base conditions is:

$Q_h = 263.65 \sqrt{50 \times 40} = 11{,}791$ cu ft per hr.

TABLE 1

Basic Orifice Factors, F_b — Flange Taps

Orifice Diam., d, Inches	Internal Diameter of Pipe, D, Inches								
	2			3			4		
	1.689	1.939	2.067	2.300	2.626	2.900	3.068	3.152	3.438
.250	12.986	12.998	13.002	13.005	13.003	12.999	12.996	12.994	12.988
.375	29.127	29.091	29.079	29.062	29.044	29.033	29.026	29.023	29.014
.500	51.941	51.746	51.680	51.591	51.510	51.466	51.444	51.346	51.410
.625	81.926	81.331	81.129	80.864	80.625	80.489	80.426	80.399	80.322
.750	119.77	118.27	117.77	117.14	116.60	116.31	116.16	116.10	115.93
.875	166.68	163.22	162.11	160.72	159.58	158.97	158.70	158.58	158.25
1.000	224.81	217.34	215.04	212.19	209.88	208.72	208.21	207.99	207.40
1.125	297.66	282.53	277.93	272.45	268.07	265.91	264.97	264.58	263.53
1.250	394.62	361.68	353.04	342.80	334.89	331.05	329.41	328.73	326.93
1.375	.....	458.85	443.44	425.28	411.40	404.87	402.10	400.95	397.94
1.500	.....	.....	554.71	522.57	499.16	488.30	483.80	481.94	477.08
1.625	.....	.....	.....	638.21	600.27	582.71	575.47	572.54	564.97
1.750	.....	.....	.....	.....	717.34	689.90	678.61	674.06	662.38
1.875	.....	.....	.....	.....	854.02	812.08	794.99	788.09	770.43
2.000	.....	.....	.....	.....	.....	951.98	926.76	916.59	890.53
2.125	.....	.....	.....	.....	.....	1116.2	1076.6	1061.9	1024.3
2.250	.....	.....	.....	.....	.....	.....	1251.2	1227.4	1174.0
2.375	.....	.....	.....	.....	.....	.....	.....	.....	1341.7
2.500	.....	.....	.....	.....	.....	.....	.....	.....	1532.7

Orifice Diam., d, Inches	Internal Diameter of Pipe, D, Inches								
	4		6				8		
	3.826	4.026	4.897	5.189	5.761	6.065	7.625	7.981	8.071
.250	12.978	12.974	.....	.....	.....	.....	.....	.....	.....
.375	29.003	28.989	.....	.....	.....	.....	.....	.....	.....
.500	51.385	51.376	51.348	51.341	51.332	51.328	.....	.....	.....
.625	80.248	80.218	80.134	80.116	80.091	80.080	.....	.....	.....
.750	115.74	115.67	115.46	115.41	115.33	115.30	.....	.....	.....
.875	157.94	157.81	157.41	157.30	157.15	157.08	156.85	156.82	156.82
1.000	206.83	206.62	205.95	205.80	205.57	205.45	205.05	204.98	204.97
1.125	262.57	262.21	261.16	260.93	260.56	260.39	259.81	259.71	259.69
1.250	325.32	324.72	323.07	322.71	322.17	321.93	321.10	320.97	320.94
1.375	395.31	394.35	391.77	391.24	390.45	390.11	388.97	388.77	388.73
1.500	472.87	471.35	467.40	466.62	465.46	464.98	463.40	463.16	463.10
1.625	558.40	556.06	550.10	548.94	547.29	546.62	544.47	544.14	544.07
1.750	652.46	648.93	640.72	638.39	636.04	635.11	632.19	631.76	631.64
1.875	755.68	750.50	737.56	735.16	731.84	730.55	726.60	726.04	725.90
2.000	868.88	861.42	842.88	839.49	834.84	833.06	827.77	827.03	826.86
2.125	993.20	982.50	956.40	951.67	945.25	942.83	935.76	934.81	934.59
2.250	1130.0	1114.9	1078.6	1072.1	1063.3	1060.0	1050.6	1049.4	1049.1
2.375	1280.8	1259.9	1210.0	1201.1	1189.2	1184.9	1172.5	1170.9	1170.5
2.500	1447.4	1419.0	1351.2	1339.3	1323.5	1317.7	1301.5	1299.4	1299.0
2.625	1632.2	1593.9	1502.9	1487.2	1466.4	1458.7	1437.6	1435.1	1434.4
2.750	1838.3	1786.7	1666.2	1645.6	1618.4	1608.3	1581.1	1577.9	1577.1
2.875	.....	2000.3	1842.3	1815.2	1779.9	1767.0	1732.2	1728.0	1727.1
3.000	.....	2245.3	2032.1	1997.1	1951.5	1935.2	1891.0	1885.8	1884.6
3.125	.....	.....	2237.3	2192.5	2134.2	2113.4	2057.7	2051.2	2049.7
3.250	.....	.....	2459.3	2402.6	2328.7	2302.4	2232.6	2224.4	2222.7
3.375	.....	.....	2700.0	2628.7	2535.9	2502.8	2415.9	2405.9	2403.7
3.500	.....	.....	2961.9	2872.5	2756.9	2715.7	2608.1	2595.9	2593.1
3.625	.....	.....	3253.7	3135.6	2992.8	2941.9	2809.4	2794.4	2791.1
3.750	.....	.....	.....	3422.2	3244.8	3182.5	3020.3	3002.1	2998.0
3.875	.....	.....	.....	3741.5	3514.4	3438.5	3240.9	3219.0	3214.2
4.000	.....	.....	.....	.....	3803.4	3711.4	3472.1	3445.7	3439.9
4.250	.....	.....	.....	.....	4454.6	4313.2	3968.3	3930.4	3922.0
4.500	.....	.....	.....	.....	.....	5013.1	4513.9	4460.4	4448.7
4.750	.....	.....	.....	.....	.....	.....	5113.1	5041.1	5024.8
5.000	.....	.....	.....	.....	.....	.....	5779.5	5678.3	5656.2
5.250	.....	.....	.....	.....	.....	.....	6515.3	6379.3	6349.6
5.500	.....	.....	.....	.....	.....	.....	7335.3	7152.3	7112.9
5.750	.....	.....	.....	.....	.....	.....	.....	8009.5	7956.0
6.000	.....	.....	.....	.....	.....	.....	.....	.....	8906.5

Orifice Diam., d, Inches	Internal Diameter of Pipe, D, Inches								
	10			12			16		
	9.564	10.020	10.136	11.376	11.938	12.090	14.688	15.000	15.250
1.000	204.79	.....	.....	.....	.....	.....	.....	.....	.....
1.125	259.36	259.29	259.27	.....	.....	.....	.....	.....	.....
1.250	320.49	320.38	320.35	320.11	320.02	320.00	.....	.....	.....
1.375	388.14	387.98	387.95	387.63	387.50	387.47	.....	.....	.....
1.500	462.31	462.11	462.07	461.64	461.48	461.44	460.86	460.81	.....
1.625	453.04	542.79	542.73	542.19	541.97	541.93	541.19	541.11	541.06
1.750	630.33	630.02	629.94	629.26	628.99	628.93	628.01	627.92	627.85
1.875	724.22	723.83	723.73	722.88	722.55	722.48	721.34	721.23	721.15
2.000	824.71	824.23	824.11	823.05	822.66	822.56	821.18	821.05	820.95
2.125	931.85	931.25	931.10	929.81	929.33	929.21	927.55	927.39	927.26
2.250	1045.6	1044.9	1044.7	1043.2	1042.6	1042.4	1040.4	1040.3	1040.1
2.375	1166.2	1165.3	1165.1	1163.2	1162.4	1162.3	1159.9	1159.7	1159.5
2.500	1293.5	1292.4	1292.1	1289.7	1288.9	1288.7	1285.9	1285.6	1285.4
2.625	1427.6	1426.2	1425.8	1423.0	1422.0	1421.7	1418.5	1418.2	1417.9
2.750	1568.5	1566.8	1566.4	1563.0	1561.8	1561.5	1557.6	1557.3	1557.0
2.875	1716.5	1714.3	1713.8	1709.7	1708.3	1707.9	1703.4	1703.0	1702.6
3.000	1871.3	1868.8	1868.2	1863.1	1861.4	1861.0	1855.7	1855.3	1854.9
3.125	2033.4	2030.2	2029.5	2023.4	2021.4	2020.9	2014.7	2014.1	2013.7
3.250	2202.6	2198.8	2197.8	2190.6	2188.2	2187.6	2180.4	2179.7	2179.2
3.375	2379.0	2374.4	2373.4	2364.7	2361.8	2361.1	2352.6	2351.9	2351.3
3.500	2563.0	2557.4	2556.1	2545.7	2542.4	2541.5	2531.6	2530.8	2530.1
3.625	2754.5	2747.8	2746.2	2733.9	2729.9	2728.9	2717.3	2716.4	2715.6
3.750	2953.8	2945.7	2943.8	2929.1	2924.3	2923.2	2909.8	2908.7	2907.9
3.875	3160.9	3151.3	3149.1	3131.6	3125.9	3124.6	3109.1	3107.7	3106.8
4.000	3376.2	3364.7	3362.1	3341.3	3334.7	3333.1	3315.1	3313.6	3312.5
4.250	3832.0	3815.7	3812.1	3783.2	3774.2	3772.0	3747.8	3745.8	3744.4
4.500	4322.9	4300.5	4295.5	4255.8	4243.5	4240.5	4208.2	4205.7	4203.8
4.750	4851.4	4820.8	4812.8	4760.1	4743.5	4739.6	4696.7	4693.6	4691.2
5.000	5420.0	5379.0	5369.9	5297.7	5275.6	5270.4	5214.0	5209.8	5206.7
5.250	6032.6	5977.5	5965.5	5870.0	5840.9	5834.0	5760.5	5755.1	5751.2
5.500	6693.1	6620.2	6604.3	6479.0	6440.9	6432.1	6336.8	6329.9	6324.8
5.750	7405.9	7310.7	7289.8	7126.6	7077.6	7066.1	6943.7	6935.0	6928.6
6.000	8176.5	8053.4	8026.3	7815.5	7752.7	7738.1	7582.2	7571.1	7563.0
6.250	9010.8	8853.2	8818.7	8548.8	8468.7	8450.0	8253.3	8239.4	8229.2
6.500	9915.5	9715.8	9672.0	9330.1	9228.5	9204.9	8958.0	8940.6	8927.9
6.750	10898	10648	10592	10163	10035	10006	9698.0	9676.2	9660.4
7.000	11979	11655	11587	11052	10893	10856	10474	10447	10428
7.250	.....	12753	12664	12001	11804	11759	11288	11255	11231
7.500	.....	13969	13851	13017	12775	12719	12141	12102	12073
7.750	.....	.....	.....	14103	13809	13741	13037	12989	12954
8.000	.....	.....	.....	15269	14912	14830	13977	13919	13877
8.250	.....	.....	.....	16528	16091	15991	14963	14894	14843
8.500	.....	.....	.....	17906	17351	17231	16001	15917	15856
8.750	.....	.....	.....	.....	18715	18564	17089	16990	16918
9.000	.....	.....	.....	.....	.....	20014	18235	18117	18031
9.250	.....	.....	.....	.....	.....	.....	19440	19300	19198
9.500	.....	.....	.....	.....	.....	.....	20709	20545	20426
9.750	.....	.....	.....	.....	.....	.....	22046	21855	21715
10.000	.....	.....	.....	.....	.....	.....	23456	23233	23070
10.250	.....	.....	.....	.....	.....	.....	24944	24685	24496
10.500	.....	.....	.....	.....	.....	.....	26518	26215	25997
10.750	.....	.....	.....	.....	.....	.....	28199	27834	27578
11.000	.....	.....	.....	.....	.....	.....	30003	29561	29253
11.250	.....	.....	.....	.....	.....	.....	.....	31414	31042

Orifice Diam., d, Inches	Internal Diameter of Pipe, D, Inches								
	20			24			30		
	18.814	19.000	19.250	22.626	23.000	23.250	28.628	29.000	29.250
2.000	819.77	819.72	819.66	.....	.....	.....	.....	.....	.....
2.125	925.86	925.80	925.72	.....	.....	.....	.....	.....	.....
2.250	1038.5	1038.4	1038.3	.....	.....	.....	.....	.....	.....
2.375	1157.5	1157.4	1157.3	1156.1	1156.0	1155.9	.....	.....	.....
2.500	1283.2	1283.0	1282.9	1281.5	1281.3	1281.3	.....	.....	.....
2.625	1415.3	1415.2	1415.0	1413.4	1413.2	1413.1	.....	.....	.....
2.750	1553.9	1553.8	1553.6	1551.8	1551.6	1551.5	.....	.....	.....
2.875	1699.1	1699.0	1698.8	1696.6	1696.4	1696.3	1694.0	.....	.....
3.000	1850.9	1850.7	1850.5	1848.0	1847.8	1847.6	1845.0	1844.8	1844.7
3.125	2009.1	2008.9	2008.7	2005.9	2005.6	2005.5	2002.6	2002.4	2002.3
3.250	2174.0	2173.8	2173.5	2170.3	2170.1	2169.9	2166.5	2166.4	2166.2
3.375	2345.5	2345.1	2344.8	2341.4	2341.1	2340.9	2337.2	2336.9	2336.8
3.500	2523.4	2523.1	2522.8	2518.8	2518.5	2518.2	2514.1	2513.9	2513.8
3.625	2708.0	2707.7	2707.3	2703.0	2702.6	2702.2	2697.7	2697.4	2697.2
3.750	2899.2	2898.9	2898.4	2893.5	2893.1	2892.8	2887.8	2887.5	2887.3
3.875	3097.0	3096.7	3096.2	3090.8	3090.2	3089.9	3084.3	3084.0	3083.8
4.000	3301.5	3301.1	3300.5	3294.4	3293.9	3293.6	3287.5	3287.2	3286.8
4.250	3730.3	3729.8	3729.2	3721.7	3721.1	3720.6	3713.3	3712.9	3712.6
4.500	4186.0	4185.3	4184.4	4175.4	4174.5	4174.0	4165.2	4164.7	4164.4
4.750	4668.3	4667.5	4666.5	4655.4	4654.4	4653.8	4643.4	4642.8	4642.4
5.000	5178.0	5176.8	5175.6	5162.1	5160.8	5160.1	5147.8	5147.1	5146.7
5.250	5714.6	5713.4	5711.8	5695.3	5694.0	5693.1	5678.5	5677.7	5677.2
5.500	6279.0	6277.3	6275.4	6255.5	6253.7	6252.7	6235.5	6234.6	6234.1
5.750	6871.0	6869.1	6866.7	6842.4	6840.5	6839.1	6819.0	6818.0	6817.3
6.000	7491.3	7488.9	7485.9	7456.5	7454.1	7452.6	7429.0	7427.7	7426.9
6.250	8140.0	8137.0	8133.4	8097.8	8095.0	8093.2	8065.4	8064.1	8063.2
6.500	8817.6	8814.0	8809.6	8766.6	8763.3	8761.1	8728.6	8726.9	8725.9
6.750	9524.5	9520.2	9514.8	9463.1	9459.1	9456.6	9418.4	9416.6	9415.4
7.000	10261	10256	10250	10188	10183	10180	10135	10133	10132
7.250	11029	11023	11015	10940	10934	10931	10879	10877	10875
7.500	11827	11820	11811	11722	11714	11710	11649	11647	11645
7.750	12658	12648	12637	12531	12524	12518	12447	12444	12442
8.000	13521	13510	13496	13371	13361	13355	13272	13268	13266
8.250	14418	14405	14388	14239	14229	14222	14126	14121	14118
8.500	15349	15334	15314	15138	15126	15118	15005	15001	14997
8.750	16316	16298	16276	16068	16053	16043	15914	15908	15904
9.000	17320	17299	17272	17030	17011	17001	16851	16843	16839
9.250	18361	18337	18305	18022	18001	17988	17815	17808	17803
9.500	19443	19414	19377	19047	19023	19008	18808	18800	18794
9.750	20565	20531	20489	20105	20078	20060	19830	19821	19815
10.000	21730	21691	21642	21198	21166	21146	20882	20871	20863
10.250	22940	22895	22838	22325	22288	22266	21963	21950	21942
10.500	24196	24144	24077	23488	23446	23420	23073	23059	23049
10.750	25502	25442	25365	24687	24639	24609	24215	24198	24188
11.000	26859	26790	26702	25925	25870	25836	25386	25367	25355
11.250	28269	28191	28089	27201	27139	27099	26588	26567	26554
11.500	29736	29646	29532	28517	28446	28402	27822	27799	27784
11.750	31262	31160	31029	29874	29794	29743	29089	29062	29045
12.000	32852	32734	32586	31275	31184	31126	30387	30357	30339
12.500	36229	36078	35888	34211	34094	34021	33084	33046	33023
13.000	39897	39707	39465	37339	37190	37098	35919	35872	35842
13.500	43897	43651	43346	40673	40488	40372	38897	38838	38801
14.000	48327	47996	47589	44232	44001	43857	42024	41952	41907
14.500	.....	.....	.....	48034	47749	47571	45306	45219	45163
15.000	.....	.....	.....	52101	51751	51533	48754	48647	48578
15.500	.....	.....	.....	56457	56029	55762	52376	52246	52162
16.000	.....	.....	.....	61129	60609	60286	56182	56024	55924
16.500	.....	.....	.....	66184	65528	65129	60183	59993	59873
17.000	.....	.....	.....	.....	70876	70369	64393	64166	64020
17.500	.....	.....	.....	.....	.....	.....	68824	68553	68380
18.000	.....	.....	.....	.....	.....	.....	73491	73169	72965
18.500	.....	.....	.....	.....	.....	.....	78410	78030	77789
19.000	.....	.....	.....	.....	.....	.....	83598	83152	82869
19.500	.....	.....	.....	.....	.....	.....	89075	88552	88221
20.000	.....	.....	.....	.....	.....	.....	94859	94252	93864

TABLE 1

Basic Orifice Factors, F_b — Pipe Taps

Orifice Diam., d, Inches	Internal Diameter of Pipe, D, Inches								
	2			3				4	
	1.689	1.939	2.067	2.300	2.626	2.900	3.068	3.152	3.438
.250	13.145	13.107	13.093	13.075	13.058	13.045	13.040	13.037	13.029
.375	30.032	29.764	29.670	29.544	29.430	29.368	29.339	29.326	29.290
.500	54.934	54.027	53.684	53.211	52.773	52.530	52.417	52.369	52.234
.625	89.211	86.865	86.010	84.823	83.670	83.002	82.687	82.553	82.173
.750	135.26	129.77	127.85	125.26	122.81	121.39	120.70	120.40	119.54
.875	197.16	185.17	181.14	175.86	171.06	168.35	167.05	166.49	164.86
1.000	281.76	256.86	248.85	238.65	229.71	224.80	222.51	221.51	218.69
1.125	400.91	350.84	335.50	316.52	300.52	292.02	288.12	286.44	281.73
1.250	....	476.67	448.03	413.79	386.01	371.74	365.31	362.57	354.98
1.375	....	....	597.35	536.71	489.65	466.27	455.95	451.60	439.68
1.500	....	....	....	694.66	616.26	578.76	562.54	555.76	537.44
1.625	....	....	....	....	772.65	713.42	688.37	678.00	650.33
1.750	....	....	....	....	968.70	876.00	837.81	822.19	781.01
1.875	....	....	....	....	....	1074.5	1016.8	993.45	932.88
2.000	....	....	....	....	....	1320.3	1233.2	1198.7	1110.4
2.125	....	....	....	....	....	....	1498.7	1447.4	1319.3
2.250	....	....	....	....	....	....	....	....	1567.1
2.375	....	....	....	....	....	....	....	....	1864.6

Orifice Diam., d, Inches	Internal Diameter of Pipe, D, Inches								
	4		6				8		
	3.826	4.026	4.897	5.189	5.716	6.065	7.625	7.981	8.071
.250	13.019	13.014	....	....	....	....	....	....	....
.375	29.253	29.239	....	....	....	....	....	....	....
.500	52.103	52.052	51.902	51.867	51.813	51.788	....	....	....
.625	81.807	81.664	81.257	81.168	81.033	80.977	....	....	....
.750	118.71	118.38	117.44	117.24	116.94	116.82	....	....	....
.875	163.23	162.58	160.71	160.30	159.71	159.46	158.65	158.54	158.52
1.000	215.87	214.72	211.36	210.63	209.53	209.09	207.65	207.45	207.40
1.125	277.11	275.26	269.75	268.53	266.69	265.94	263.52	263.18	263.09
1.250	347.66	344.77	331.15	334.34	331.45	330.26	326.41	325.86	325.74
1.375	428.39	424.00	411.28	408.45	404.14	402.34	396.50	395.68	395.48
1.500	520.42	513.89	495.30	491.24	485.07	482.50	474.01	472.78	472.51
1.625	625.12	615.59	588.93	583.21	574.60	571.03	559.14	557.41	557.01
1.750	744.22	730.52	692.91	684.98	673.16	668.30	652.12	649.75	649.20
1.875	879.89	860.47	808.10	797.26	781.28	774.75	753.22	750.04	749.31
2.000	1034.9	1007.6	935.53	920.91	899.54	890.89	862.67	858.53	857.57
2.125	1212.5	1174.7	1076.4	1056.9	1028.6	1017.3	980.76	957.02	974.22
2.250	1417.2	1365.0	1232.3	1206.4	1169.4	1154.7	1107.8	1101.1	1099.5
2.375	1654.3	1582.8	1404.9	1334.1	1322.7	1303.8	1244.2	1235.7	1233.8
2.500	1930.9	1833.4	1586.3	1552.0	1489.8	1465.6	1390.4	1379.7	1377.3
2.625	2256.6	2123.5	1808.8	1751.5	1671.8	1641.0	1546.7	1533.6	1530.6
2.750	....	2462.2	2045.6	1971.8	1870.2	1831.3	1713.8	1697.7	1694.1
2.875	....	....	2310.3	2215.5	2098.7	2037.9	1892.3	1872.6	1868.1
3.000	....	....	2607.0	2485.9	2323.3	2262.3	2082.7	2058.8	2053.4
3.125	....	....	2941.1	2786.8	2582.2	2506.3	2285.9	2257.0	2250.4
3.250	....	....	3319.2	3122.8	2866.0	2772.0	2502.6	2467.7	2459.8
3.375	....	....	3749.6	3498.3	3178.1	3061.9	2733.8	2691.9	2682.5
3.500	....	....	....	3823.6	3521.9	3378.7	2980.5	2930.4	2919.1
3.625	....	....	....	4404.4	3901.8	3725.7	3243.8	3184.0	3170.6
3.750	....	....	....	....	4323.2	4106.8	3525.0	3454.0	3437.6
3.875	....	....	....	....	4792.3	4526.5	3825.6	3741.4	3722.6
4.000	....	....	....	....	5316.8	4990.2	4147.1	4047.7	4025.4
4.250	....	....	....	....	....	....	4860.3	4722.4	4691.8
4.500	....	....	....	....	....	....	5682.0	5492.1	5450.1
4.750	....	....	....	....	....	....	6633.9	6373.9	6316.8
5.000	....	....	....	....	....	....	7744.9	7389.9	7312.5
5.250	....	....	....	....	....	....	9053.1	8568.3	8463.7
5.500	....	....	....	....	....	....	....	9946.7	9804.8

Orifice Diam., d, Inches	Internal Diameter of Pipe, D, Inches								
	10			12			16		
	9.564	10.020	10.136	11.376	11.938	12.090	14.688	15.000	15.250
1.000	206.79	....	....	....	....	....	....	....	....
1.125	262.09	261.88	261.83	....	....	....	....	....	....
1.250	324.16	323.82	323.74	323.08	322.80	322.73	....	....	....
1.375	393.10	392.59	392.47	391.43	391.06	390.97	....	....	....
1.500	469.03	468.28	468.12	466.62	466.08	465.95	464.32	464.18	....
1.625	552.09	551.04	550.80	548.67	547.94	547.75	545.49	545.29	545.14
1.750	642.42	640.97	640.64	637.73	636.72	636.46	633.37	633.11	632.90
1.875	740.20	738.24	737.80	733.87	732.51	732.17	728.04	727.70	727.42
2.000	845.58	843.01	842.42	837.24	835.45	835.00	829.58	829.11	828.76
2.125	958.76	955.43	954.67	947.96	945.63	945.05	938.03	937.43	936.97
2.250	1079.9	1075.7	1074.7	1066.2	1063.2	1062.4	1053.5	1053.2	1052.1
2.375	1209.3	1204.0	1202.8	1192.0	1188.2	1187.3	1176.1	1175.1	1174.4
2.500	1347.1	1340.5	1339.0	1325.6	1321.0	1319.8	1305.8	1304.6	1303.7
2.625	1493.5	1485.4	1483.6	1467.2	1461.4	1460.1	1442.8	1441.4	1440.2
2.750	1648.7	1639.0	1636.7	1616.9	1610.0	1608.2	1587.3	1585.4	1584.1
2.875	1813.1	1801.4	1798.7	1774.9	1766.5	1761.5	1739.1	1737.0	1735.3
3.000	1987.0	1973.0	1969.7	1941.3	1931.4	1928.9	1898.6	1896.1	1894.1
3.125	2170.7	2154.0	2150.1	2116.4	2104.7	2101.8	2065.8	2062.8	2060.5
3.250	2364.6	2344.7	2340.2	2300.4	2286.6	2283.2	2240.9	2237.3	2234.6
3.375	2569.1	2545.6	2540.3	2401.5	2477.3	2473.4	2423.9	2419.7	2416.5
3.500	2784.7	2757.1	2750.8	2696.0	2677.2	2672.5	2615.1	2610.2	2606.5
3.625	3011.8	2979.5	2972.1	2908.2	2886.3	2880.8	2814.5	2818.0	2804.5
3.750	3250.9	3213.2	3204.6	3130.3	3104.9	3098.7	3022.2	3015.7	3010.7
3.875	3502.8	3458.8	3448.8	3362.7	3333.4	3326.2	3238.5	3231.0	3225.3
4.000	3767.9	3716.8	3705.2	3605.7	3572.0	3563.8	3463.4	3454.9	3448.4
4.250	4341.1	4274.5	4257.0	4125.2	4080.9	4070.2	3939.9	3928.9	3920.7
4.500	4976.6	4885.7	4865.1	4692.2	4634.6	4620.6	4453.2	4439.3	4428.8
4.750	5682.2	5562.5	5530.7	5310.5	5236.3	5218.3	5005.0	4987.6	4974.3
5.000	6467.1	6310.6	6275.5	5984.7	5889.8	5866.8	5597.3	5575.4	5558.9
5.250	7342.2	7138.9	7093.4	6720.0	6599.4	6570.4	6232.1	6204.9	6184.4
5.500	8320.5	8057.7	7999.2	7522.7	7370.2	7333.7	6911.9	6878.2	6853.0
5.750	9418.0	9079.7	9004.9	8399.6	8208.1	8162.4	7639.2	7597.8	7566.9
6.000	10654	10220	10125	9359.2	9119.7	9062.8	8417.1	8366.7	8328.8
6.250	12053	11498	11376	10411	10113	10042	9248.8	9187.6	9141.8
6.500	13646	12934	12779	11566	11196	11109	10138	10064	10009
6.750	....	14556	14360	12838	12380	12273	11089	11000	10934
7.000	....	16403	16152	14242	13677	13545	12108	12001	11921
7.250	....	....	....	15796	15100	14939	13198	13070	12974
7.500	....	....	....	17524	16667	16470	14366	14212	14099
7.750	....	....	....	19453	18398	18157	15618	15436	15301
8.000	....	....	....	....	20316	20020	16963	16746	16587
8.250	....	....	....	....	22450	22088	18408	18153	17964
8.500	....	....	....	....	....	....	19964	19662	19439
8.750	....	....	....	....	....	....	21641	21284	21022
9.000	....	....	....	....	....	....	23451	23031	22723
9.250	....	....	....	....	....	....	25410	24914	24553
9.500	....	....	....	....	....	....	27534	26950	26526
9.750	....	....	....	....	....	....	29841	29154	28656
10.000	....	....	....	....	....	....	32354	31546	30962
10.250	....	....	....	....	....	....	35101	34148	33462
10.500	....	....	....	....	....	....	....	36989	36182

Orifice Diam., d, Inches	Internal Diameter of Pipe, D, Inches								
	20			24			30		
	18.814	19.000	19.250	22.626	23.000	23.250	28.628	29.000	29.250
2.000	825.20	825.06	824.88	....	....	....	....	....	....
2.125	932.40	932.24	932.01	....	....	....	....	....	....
2.250	1046.3	1046.1	1045.8	....	....	....	....	....	....
2.375	1167.2	1166.8	1166.5	1162.9	1162.5	1162.3	....	....	....
2.500	1294.7	1294.4	1294.0	1289.5	1289.1	1288.8	....	....	....
2.625	1429.2	1428.8	1428.3	1422.8	1422.1	1422.1	....	....	....
2.750	1570.7	1570.2	1569.6	1562.9	1562.3	1562.0	....	....	....
2.875	1719.2	1718.6	1717.8	1709.8	1709.2	1708.7	1701.9	....	....
3.000	1874.7	1874.1	1873.2	1863.7	1862.8	1862.3	1854.2	1853.8	1853.5
3.125	2037.5	2036.6	2035.6	2024.3	2023.3	2022.7	2013.2	2012.8	2012.5
3.250	2207.5	2206.4	2205.2	2191.9	2190.8	2190.1	2179.0	2178.4	2178.1
3.375	2384.7	2383.6	2382.1	2366.5	2365.3	2364.5	2351.5	2350.9	2350.4
3.500	2569.5	2568.1	2566.3	2548.3	2546.8	2545.8	2530.8	2530.0	2529.6
3.625	2761.6	2760.0	2758.0	2737.1	2735.3	2734.3	2716.9	2716.1	2715.4
3.750	2961.4	2959.5	2957.2	2933.1	2931.1	2929.7	2909.8	2908.9	2908.2
3.875	3168.7	3166.7	3163.9	3136.3	3134.0	3132.5	3109.7	3108.6	3107.8
4.000	3383.8	3381.5	3378.4	3346.8	3344.1	3342.5	3316.5	3315.2	3314.4
4.250	3837.6	3834.6	3861.3	3789.9	3786.5	3784.4	3750.9	3749.3	3748.3
4.500	4323.7	4319.8	4314.8	4263.1	4258.8	4256.1	4213.7	4211.7	4210.3
4.750	4842.6	4837.8	4831.6	4766.8	4761.5	4758.0	4705.0	4702.5	4700.7
5.000	5395.5	5389.5	5381.7	5301.8	5295.0	5290.8	5225.3	5222.0	5220.0
5.250	5983.1	5975.8	5966.3	5868.6	5860.4	5855.1	5774.8	5770.9	5768.3
5.500	6606.6	6597.7	6586.3	6467.8	6457.9	6451.6	6354.2	6349.5	6346.4
5.750	7267.2	7256.6	7242.7	7100.4	7088.5	7080.9	6963.7	6958.0	6954.3
6.000	7966.4	7953.6	7936.9	7766.8	7752.7	7743.6	7604.0	7597.1	7592.7
6.250	8705.5	8690.1	8670.3	8468.0	8451.4	8440.6	8275.3	8267.2	8262.0
6.500	9485.9	9467.7	9444.1	9205.1	9185.3	9172.6	8978.4	8969.0	8962.7
6.750	10310	10289	10260	9978.6	9955.5	9940.6	9713.6	9702.6	9695.3
7.000	11178	11153	11120	10790	10763	10746	10482	10469	10460
7.250	12094	12064	12025	11640	11608	11589	11283	11268	11258
7.500	13060	13025	12980	12530	12494	12470	12119	12101	12090
7.750	14077	14037	13983	13462	13420	13393	12988	12969	12955
8.000	15149	15101	15040	14436	14387	14357	13893	13871	13856
8.250	16279	16224	16153	15455	15399	15364	14833	14809	14792
8.500	17464	17405	17323	16520	16456	16416	15811	15783	15764
8.750	18725	18650	18555	17632	17559	17513	16827	16794	16773
9.000	20047	19962	19853	18794	18711	18659	17881	17844	17820
9.250	21443	21344	21218	20008	19914	19854	18973	18932	18905
9.500	22915	22803	22659	21277	21169	21101	20107	20060	20031
9.750	24471	24341	24176	22600	22480	22402	21282	21230	21196
10.000	26114	25966	25776	23984	23846	23759	22499	22441	22403
10.250	27851	27681	27464	25429	25274	25176	23760	23696	23654
10.500	29688	29495	29247	26939	26764	26653	25057	24994	24947
10.750	31634	31413	31132	28517	28329	28195	26419	26339	26287
11.000	33695	33443	33123	30166	29944	29804	27819	27730	27672
11.250	35882	35596	35232	31890	31641	31484	29769	29170	29105
11.500	38204	37879	37465	33693	33415	33239	30769	30659	30588
11.750	40672	40303	39834	35580	35268	35071	32322	32200	32122
12.000	43300	42881	42348	37555	37207	36987	33929	33795	33708
12.500	49091	48549	47862	41791	41356	41081	37314	37150	37045
13.000	55711	55011	54127	46447	45906	45565	40941	40742	40614
13.500	....	....	....	51576	50904	50483	44827	44588	44433
14.000	....	....	....	57242	56411	55890	48996	48706	48520
14.500	....	....	....	63522	62494	61854	53469	53122	52899
15.000	....	....	....	70509	69238	68449	58273	57858	57591
15.500	....	....	....	78317	76745	75772	63438	62943	62626
16.000	....	....	....	....	85139	83936	68999	68411	68033
16.500	....	....	....	....	....	....	74994	74295	73848
17.000	....	....	....	....	....	....	81466	80638	80108
17.563	....	....	....	....	....	....	88467	87485	86859
18.000	....	....	....	....	....	....	96032	94891	94152
18.500	....	....	....	....	....	....	104287	102916	102044
19.000	....	....	....	....	....	....	113258	111631	110608
19.500	....	....	....	....	....	....	123057	121134	119917
20.000	....	....	....	....	....	....	133777	131507	130064

TABLE 2

Pipe Diameter Factors, F_d — Flange Taps

Internal Diameter of Pipe, *D*, inches

β	1.689	1.939	2.067	2.300	2.626	2.900	3.068	3.152	3.438	3.826	4.026
	2			3				4			
0.10	0.1062	0.1027	0.1012	0.0987	0.0958	0.0928	0.0927	0.0921	0.0905	0.0886	0.0877
0.11	0.1020	0.0985	0.0970	0.0945	0.0916	0.0896	0.0885	0.0880	0.0863	0.0844	0.0835
0.12	0.0981	0.0945	0.0930	0.0905	0.0876	0.0856	0.0845	0.0840	0.0823	0.0804	0.0795
0.13	0.0943	0.0907	0.0892	0.0867	0.0838	0.0818	0.0807	0.0802	0.0785	0.0766	0.0757
0.14	0.0906	0.0871	0.0856	0.0831	0.0802	0.0782	0.0771	0.0765	0.0749	0.0730	0.0721
0.15	0.0872	0.0837	0.0822	0.0797	0.0768	0.0748	0.0736	0.0731	0.0715	0.0696	0.0687
0.16	0.0840	0.0805	0.0789	0.0764	0.0736	0.0715	0.0704	0.0699	0.0682	0.0663	0.0654
0.17	0.0809	0.0774	0.0759	0.0734	0.0705	0.0685	0.0673	0.0668	0.0652	0.0633	0.0624
0.18	0.0780	0.0745	0.0730	0.0705	0.0676	0.0656	0.0645	0.0639	0.0623	0.0604	0.0595
0.19	0.0753	0.0718	0.0703	0.0678	0.0649	0.0629	0.0617	0.0612	0.0596	0.0577	0.0568
0.20	0.0728	0.0693	0.0677	0.0653	0.0624	0.0603	0.0592	0.0587	0.0570	0.0551	0.0542
0.21	0.0703	0.0668	0.0652	0.0628	0.0599	0.0579	0.0567	0.0562	0.0546	0.0527	0.0518
0.22	0.0681	0.0546	0.0630	0.0606	0.0577	0.0556	0.0545	0.0540	0.0524	0.0505	0.0496
0.23	0.0660	0.0625	0.0610	0.0585	0.0556	0.0536	0.0525	0.0520	0.0503	0.0484	0.0475
0.24	0.0542	0.0505	0.0591	0.0566	0.0538	0.0517	0.0506	0.0501	0.0484	0.0465	0.0457
0.25	0.0524	0.0589	0.0574	0.0549	0.0520	0.0500	0.0489	0.0483	0.0467	0.0448	0.0439
0.26	0.0507	0.0572	0.0557	0.0532	0.0504	0.0483	0.0472	0.0467	0.0451	0.0431	0.0423
0.27	0.0593	0.0558	0.0543	0.0518	0.0489	0.0469	0.0458	0.0452	0.0436	0.0417	0.0408
0.28	0.0580	0.0545	0.0530	0.0505	0.0476	0.0456	0.0445	0.0440	0.0423	0.0404	0.0395
0.29	0.0559	0.0534	0.0518	0.0494	0.0465	0.0444	0.0433	0.0428	0.0412	0.0393	0.0384
0.30	0.0559	0.0524	0.0508	0.0484	0.0455	0.0434	0.0423	0.0418	0.0402	0.0383	0.0374
0.31	0.0549	0.0514	0.0499	0.0474	[illegible]	0.0425	0.0414	0.0409	0.0392	0.0373	0.0364
0.32	0.0541	0.0506	0.0491	0.0467	[illegible]	0.0417	0.0406	0.0401	0.0385	0.0366	0.0357
0.33	0.0534	0.0499	0.0484	0.0460	[illegible]	0.0411	0.0399	0.0394	0.0378	0.0359	0.0350
0.34	0.0529	0.0495	0.0479	0.0455	0.0426	0.0406	0.0395	0.0389	0.0373	0.0354	0.0345
0.35	0.0525	0.0490	0.0475	0.0450	0.0422	0.0401	0.0390	0.0385	0.0369	0.0350	0.0341
0.36	0.0521	0.0487	0.0471	0.0447	0.0418	0.0398	0.0387	0.0382	0.0366	0.0347	0.0338
0.37	0.0520	0.0485	0.0470	0.0446	0.0417	0.0397	0.0386	0.0380	0.0364	0.0345	0.0337
0.38	0.0519	0.0484	0.0469	0.0445	0.0416	0.0396	0.0385	0.0380	0.0363	0.0344	0.0336
0.39	0.0520	0.0485	0.0470	0.0445	0.0417	0.0397	0.0386	0.0380	0.0364	0.0345	0.0337
0.40	0.0521	0.0486	0.0471	0.0446	0.0418	0.0398	0.0387	0.0382	0.0365	0.0346	0.0338
0.41	0.0523	0.0488	0.0473	0.0449	0.0420	0.0400	0.0389	0.0384	0.0368	0.0349	0.0340
0.42	0.0526	0.0491	0.0476	0.0452	0.0423	0.0403	0.0392	0.0387	0.0371	0.0352	0.0343
0.43	0.0530	0.0495	0.0480	0.0456	0.0427	0.0407	0.0396	0.0391	0.0375	0.0356	0.0348
0.44	0.0534	0.0500	0.0485	0.0461	0.0432	0.0412	0.0401	0.0396	0.0380	0.0361	0.0353
0.45	0.0540	0.0506	0.0490	0.0466	0.0438	0.0418	0.0407	0.0402	0.0386	0.0367	0.0359
0.46	0.0546	0.0512	0.0497	0.0473	0.0445	0.0425	0.0414	0.0409	0.0393	0.0374	0.0365
0.47	0.0553	0.0519	0.0504	0.0479	0.0451	0.0431	0.0421	0.0415	0.0400	0.0381	0.0372
0.48	0.0561	0.0527	0.0512	0.0488	0.0459	0.0440	0.0429	0.0424	0.0408	0.0389	0.0380
0.49	0.0559	0.0535	0.0520	0.0496	0.0468	0.0448	0.0437	0.0432	0.0416	0.0397	0.0389
0.50	0.0578	0.0544	0.0529	0.0505	0.0477	0.0457	0.0446	0.0441	0.0426	0.0407	0.0398
0.51	0.0587	0.0553	0.0538	0.0514	0.0486	0.0467	0.0456	0.0451	0.0435	0.0417	0.0408
0.52	0.0598	0.0564	0.0549	0.0525	0.0497	0.0478	0.0467	0.0462	0.0446	0.0427	0.0419
0.53	0.0608	0.0574	0.0559	0.0535	0.0508	0.0488	0.0477	0.0472	0.0457	0.0438	0.0430
0.54	0.0617	0.0584	0.0569	0.0546	0.0518	0.0498	0.0488	0.0483	0.0467	0.0449	0.0440
0.55	0.0629	0.0595	0.0580	0.0557	0.0529	0.0510	0.0499	0.0494	0.0479	0.0460	0.0452
0.56	0.0639	0.0606	0.0591	0.0568	0.0540	0.0521	0.0511	0.0506	0.0490	0.0472	0.0464
0.57	0.0651	0.0618	0.0603	0.0580	0.0553	0.0534	0.0523	0.0518	0.0503	0.0484	0.0476
0.58	0.0663	0.0630	0.0615	0.0592	0.0565	0.0545	0.0535	0.0530	0.0515	0.0496	0.0488
0.59	0.0675	0.0642	0.0628	0.0505	0.0578	0.0558	0.0548	0.0543	0.0528	0.0510	0.0501
0.60	0.0687	0.0654	0.0640	0.0617	0.0590	0.0571	0.0560	0.0556	0.0540	0.0522	0.0514
0.61	0.0698	0.0666	0.0651	0.0628	0.0602	0.0583	0.0572	0.0567	0.0552	0.0534	0.0526
0.62	0.0711	0.0678	0.0664	0.0641	0.0614	0.0595	0.0585	0.0580	0.0565	0.0548	0.0529
0.63	0.0722	0.0690	0.0676	0.0653	0.0625	0.0608	0.0597	0.0593	0.0578	0.0560	0.0552
0.64	0.0733	0.0701	0.0687	0.0665	0.0638	0.0620	0.0610	0.0605	0.0590	0.0572	0.0564
0.65	0.0745	0.0713	0.0699	0.0677	0.0651	0.0632	0.0622	0.0617	0.0602	0.0585	0.0577
0.66	0.0756	0.0724	0.0710	0.0688	0.0662	0.0643	0.0633	0.0629	0.0614	0.0597	0.0589
0.67	0.0766	0.0735	0.0721	0.0699	0.0673	0.0655	0.0645	0.0640	0.0626	0.0608	0.0601
0.68	0.0777	0.0745	0.0732	0.0710	0.0684	0.0666	0.0656	0.0652	0.0637	0.0620	0.0612
0.69	0.0786	0.0755	0.0741	0.0720	0.0694	0.0676	0.0667	0.0662	0.0648	0.0631	0.0623
0.70	0.0795	0.0765	0.0751	0.0730	0.0704	0.0687	0.0677	0.0672	0.0658	0.0641	0.0634
0.71	0.0803	0.0773	0.0759	0.0738	0.0713	0.0695	0.0686	0.0681	0.0667	0.0651	0.0643
0.72	0.0811	0.0781	0.0768	0.0747	0.0722	0.0704	0.0695	0.0690	0.0676	0.0660	0.0652
0.73	0.0818	0.0789	0.0776	0.0755	0.0730	0.0713	0.0704	0.0699	0.0685	0.0669	0.0662
0.74	0.0825	0.0795	0.0782	0.0762	0.0738	0.0721	0.0711	0.0707	0.0693	0.0677	0.0670
0.75	0.0829	0.0800	0.0788	0.0767	0.0743	0.0726	0.0718	0.0713	0.0699	0.0683	0.0677

Internal Diameter of Pipe, *D*, inches

β	4.897	5.189	5.761	6.065	7.625	7.981	8.071	9.564	10.020	10.136	11.376	11.938	12.090
	6				8			10			12		
0.10	0.0845	0.0836	0.0821	0.0814	0.0784	0.0778	0.0777	0.0757	0.0752	0.0751	0.0739	0.0734	0.0733
0.11	0.0803	0.0795	0.0779	0.0772	0.0742	0.0736	0.0735	0.0716	0.0710	0.0709	0.0697	0.0692	0.0691
0.12	0.0763	0.0755	0.0739	0.0732	0.0702	0.0696	0.0695	0.0676	0.0570	0.0569	0.0657	0.0652	0.0651
0.13	0.0725	0.0717	0.0701	0.0694	0.0664	0.0558	0.0657	0.0538	0.0632	0.0631	0.0619	0.0614	0.0613
0.14	0.0689	0.0680	0.0665	0.0658	0.0628	0.0622	0.0621	0.0501	0.0596	0.0595	0.0583	0.0578	0.0577
0.15	0.0655	0.0646	0.0631	0.0624	0.0594	0.0588	0.0587	0.0567	0.0562	0.0561	0.0549	0.0544	0.0543
0.16	0.0623	0.0614	0.0599	0.0591	0.0561	0.0556	0.0554	0.0535	0.0530	0.0528	0.0516	0.0512	0.0510
0.17	0.0592	0.0583	0.0568	0.0561	0.0531	0.0525	0.0524	0.0504	0.0499	0.0498	0.0486	0.0481	0.0480
0.18	0.0553	0.0554	0.0539	0.0532	0.0502	0.0496	0.0495	0.0475	0.0470	0.0469	0.0457	0.0452	0.0451
0.19	0.0536	0.0527	0.0512	0.0505	0.0475	0.0469	0.0468	0.0448	0.0443	0.0442	0.0430	0.0425	0.0424
0.20	0.0511	0.0502	0.0487	0.0479	0.0449	0.0444	0.0442	0.0423	0.0418	0.0416	0.0404	0.0400	0.0398
0.21	0.0486	0.0477	0.0462	0.0455	0.0425	0.0419	0.0418	0.0398	0.0393	0.0392	0.0380	0.0375	0.0374
0.22	0.0464	0.0455	0.0440	0.0433	0.0403	0.0397	0.0396	0.0376	0.0371	0.0370	0.0358	0.0353	0.0352
0.23	0.0444	0.0435	0.0420	0.0412	0.0382	0.0377	0.0375	0.0356	0.0351	0.0350	0.0338	0.0333	0.0332
0.24	0.0425	0.0416	0.0401	0.0393	0.0364	0.0358	0.0357	0.0337	0.0332	0.0331	0.0319	0.0314	0.0313
0.25	0.0407	0.0399	0.0383	0.0376	0.0346	0.0341	0.0339	0.0320	0.0315	0.0313	0.0301	0.0297	0.0295
0.26	0.0391	0.0382	0.0367	0.0360	0.0330	0.0324	0.0323	0.0303	0.0298	0.0297	0.0285	0.0280	0.0279
0.27	0.0377	0.0368	0.0353	0.0345	0.0315	0.0310	0.0309	0.0289	0.0284	0.0283	0.0271	0.0266	0.0265
0.28	0.0364	0.0355	0.0340	0.0332	0.0303	0.0297	0.0296	0.0276	0.0271	0.0270	0.0258	0.0253	0.0252
0.29	0.0352	0.0343	0.0328	0.0321	0.0291	0.0286	0.0284	0.0265	0.0260	0.0258	0.0246	0.0242	0.0240
0.30	0.0342	0.0333	0.0318	0.0311	0.0281	0.0275	0.0274	0.0255	0.0249	0.0248	0.0236	0.0231	0.0230
0.31	0.0333	0.0324	0.0309	0.0302	0.0272	0.0266	0.0265	0.0245	0.0240	0.0239	0.0227	0.0222	0.0221
0.32	0.0325	0.0317	0.0301	0.0294	0.0264	0.0259	0.0257	0.0238	0.0233	0.0232	0.0220	0.0215	0.0214
0.33	0.0319	0.0310	0.0295	0.0288	0.0258	0.0252	0.0251	0.0231	0.0226	0.0225	0.0213	0.0208	0.0207
0.34	0.0314	0.0305	0.0290	0.0283	0.0253	0.0247	0.0246	0.0226	0.0221	0.0220	0.0208	0.0203	0.0202
0.35	0.0310	0.0301	0.0286	0.0278	0.0249	0.0243	0.0242	0.0222	0.0217	0.0216	0.0204	0.0199	0.0198
0.36	0.0306	0.0298	0.0283	0.0275	0.0246	0.0240	0.0239	0.0219	0.0214	0.0213	0.0201	0.0196	0.0195
0.37	0.0305	0.0296	0.0281	0.0274	0.0244	0.0239	0.0237	0.0218	0.0213	0.0212	0.0200	0.0195	0.0194
0.38	0.0304	0.0285	0.0280	0.0273	0.0244	0.0238	0.0237	0.0217	0.0212	0.0211	0.0199	0.0195	0.0193
0.39	0.0305	0.0296	0.0281	0.0274	0.0244	0.0239	0.0238	0.0218	0.0213	0.0212	0.0200	0.0195	0.0194
0.40	0.0306	0.0296	0.0283	0.0276	0.0246	0.0240	0.0239	0.0220	0.0215	0.0213	0.0202	0.0197	0.0196
0.41	0.0309	0.0300	0.0285	0.0278	0.0248	0.0243	0.0241	0.0222	0.0217	0.0216	0.0204	0.0199	0.0198
0.42	0.0312	0.0303	0.0288	0.0281	0.0252	0.0246	0.0245	0.0226	0.0221	0.0219	0.0208	0.0203	0.0202
0.43	0.0316	0.0308	0.0293	0.0286	0.0256	0.0251	0.0249	0.0230	0.0225	0.0224	0.0212	0.0207	0.0206
0.44	0.0321	0.0313	0.0298	0.0291	0.0261	0.0256	0.0254	0.0235	0.0230	0.0229	0.0217	0.0213	0.0211
0.45	0.0327	0.0319	0.0304	0.0297	0.0267	0.0262	0.0261	0.0241	0.0236	0.0235	0.0223	0.0219	0.0217
0.46	0.0334	0.0326	0.0311	0.0304	0.0274	0.0269	0.0267	0.0248	0.0243	0.0242	0.0230	0.0226	0.0224
0.47	0.0341	0.0333	0.0318	0.0311	0.0282	0.0276	0.0275	0.0256	0.0251	0.0249	0.0238	0.0233	0.0232
0.48	0.0350	0.0341	0.0326	0.0319	0.0290	0.0284	0.0283	0.0264	0.0259	0.0258	0.0246	0.0242	0.0240
0.49	0.0358	0.0349	0.0335	0.0328	0.0299	0.0293	0.0292	0.0273	0.0268	0.0267	0.0255	0.0250	0.0249
0.50	0.0368	0.0359	0.0344	0.0337	0.0308	0.0303	0.0302	0.0283	0.0278	0.0276	0.0265	0.0260	0.0259
0.51	0.0378	0.0369	0.0354	0.0347	0.0318	0.0313	0.0312	0.0293	0.0288	0.0287	0.0275	0.0270	0.0269
0.52	0.0388	0.0380	0.0365	0.0358	0.0329	0.0324	0.0323	0.0304	0.0299	0.0298	0.0286	0.0281	0.0280
0.53	0.0399	0.0391	0.0376	0.0369	0.0340	0.0335	0.0334	0.0315	0.0310	0.0309	0.0297	0.0293	0.0291
0.54	0.0410	0.0402	0.0387	0.0380	0.0351	0.0346	0.0345	0.0326	0.0321	0.0320	0.0308	0.0304	0.0303
0.55	0.0422	0.0413	0.0399	0.0392	0.0363	0.0358	0.0357	0.0338	0.0333	0.0332	0.0321	0.0316	0.0315
0.56	0.0433	0.0425	0.0411	0.0404	0.0375	0.0370	0.0369	0.0350	0.0345	0.0344	0.0333	0.0328	0.0327
0.57	0.0446	0.0438	0.0423	0.0416	0.0388	0.0383	0.0381	0.0363	0.0358	0.0357	0.0346	0.0341	0.0340
0.58	0.0458	0.0450	0.0436	0.0429	0.0401	0.0395	0.0394	0.0376	0.0371	0.0370	0.0358	0.0354	0.0353
0.59	0.0472	0.0463	0.0449	0.0442	0.0414	0.0409	0.0408	0.0389	0.0384	0.0383	0.0372	0.0367	0.0366
0.60	0.0484	0.0476	0.0462	0.0455	0.0427	0.0422	0.0421	0.0402	0.0398	0.0397	0.0385	0.0381	0.0380
0.61	0.0497	0.0489	0.0474	0.0468	0.0440	0.0435	0.0433	0.0415	0.0411	0.0409	0.0396	0.0394	0.0393
0.62	0.0510	0.0502	0.0488	0.0481	0.0402	0.0448	0.0447	0.0429	0.0424	0.0423	0.0412	0.0407	0.0406
0.63	0.0523	0.0515	0.0501	0.0494	0.0466	0.0461	0.0460	0.0442	0.0437	0.0436	0.0425	0.0421	0.0420
0.64	0.0535	0.0527	0.0513	0.0507	0.0479	0.0474	0.0473	0.0455	0.0451	0.0449	0.0438	0.0434	0.0433
0.65	0.0548	0.0540	0.0526	0.0520	0.0492	0.0487	0.0486	0.0468	0.0464	0.0463	0.0452	0.0447	0.0446
0.66	0.0560	0.0552	0.0538	0.0532	0.0505	0.0500	0.0499	0.0481	0.0476	0.0475	0.0465	0.0460	0.0459
0.67	0.0572	0.0564	0.0551	0.0544	0.0517	0.0512	0.0511	0.0494	0.0489	0.0488	0.0477	0.0473	0.0472
0.68	0.0584	0.0576	0.0563	0.0556	0.0530	0.0525	0.0523	0.0506	0.0502	0.0500	0.0490	0.0486	0.0484
0.69	0.0595	0.0587	0.0574	0.0567	0.0541	0.0536	0.0535	0.0518	0.0513	0.0512	0.0502	0.0497	0.0496
0.70	0.0606	0.0598	0.0585	0.0579	0.0552	0.0548	0.0546	0.0529	0.0525	0.0524	0.0513	0.0509	0.0508
0.71	0.0616	0.0608	0.0595	0.0589	0.0563	0.0558	0.0557	0.0540	0.0535	0.0534	0.0524	0.0520	0.0519
0.72	0.0625	0.0618	0.0605	0.0599	0.0573	0.0568	0.0567	0.0550	0.0546	0.0545	0.0535	0.0530	0.0529
0.73	0.0635	0.0627	0.0614	0.0608	0.0583	0.0578	0.0577	0.0560	0.0556	0.0555	0.0545	0.0541	0.0540
0.74	0.0643	0.0636	0.0623	0.0617	0.0592	0.0587	0.0586	0.0570	0.0565	0.0564	0.0554	0.0550	0.0549
0.75	0.0650	0.0643	0.0630	0.0624	0.0539	0.0594	0.0594	0.0577	0.0573	0.0572	0.0562	0.0558	0.0557

Internal Diameter of Pipe, *D*, inches

β	14.688	15.000	15.250	18.814	19.000	19.250	22.626	23.000	23.250	28.628	29.000	29.250
	16			20			24			30		
0.10	0.0715	0.0713	0.0711	0.0694	0.0693	0.0692	0.0680	0.0579	0.0678	0.0664	0.0663	0.0663
0.11	0.0673	0.0671	0.0670	0.0652	0.0651	0.0550	0.0538	0.0637	0.0636	0.0622	0.0621	0.0621
0.12	0.0633	0.0631	0.0630	0.0612	0.0611	0.0610	0.0598	0.0597	0.0596	0.0582	0.0581	0.0581
0.13	0.0595	0.0593	0.0592	0.0574	0.0573	0.0572	0.0560	0.0559	0.0558	0.0544	0.0543	0.0543
0.14	0.0559	0.0557	0.0555	0.0538	0.0537	0.0535	0.0524	0.0523	0.0522	0.0508	0.0507	0.0507
0.15	0.0525	0.0523	0.0521	0.0504	0.0503	0.0502	0.0490	0.0489	0.0488	0.0474	0.0473	0.0473
0.16	0.0492	0.0490	0.0489	0.0471	0.0471	0.0469	0.0457	0.0456	0.0455	0.0441	0.0441	0.0440
0.17	0.0461	0.0460	0.0458	0.0441	0.0440	0.0439	0.0427	0.0426	0.0425	0.0411	0.0410	0.0409
0.18	0.0433	0.0431	0.0429	0.0412	0.0411	0.0410	0.0398	0.0397	0.0396	0.0382	0.0381	0.0381
0.19	0.0406	0.0404	0.0402	0.0385	0.0384	0.0383	0.0371	0.0370	0.0369	0.0355	0.0354	0.0354
0.20	0.0380	0.0378	0.0377	0.0359	0.0359	0.0358	0.0345	0.0344	0.0344	0.0330	0.0329	0.0328
0.21	0.0356	0.0354	0.0353	0.0335	0.0334	0.0333	0.0321	0.0320	0.0319	0.0305	0.0305	0.0304
0.22	0.0334	0.0332	0.0330	0.0313	0.0312	0.0311	0.0299	0.0298	0.0297	0.0283	0.0282	0.0282
0.23	0.0313	0.0311	0.0310	0.0293	0.0292	0.0291	0.0279	0.0278	0.0277	0.0263	0.0262	0.0261
0.24	0.0294	0.0293	0.0291	0.0274	0.0273	0.0272	0.0260	0.0259	0.0258	0.0244	0.0243	0.0243
0.25	0.0277	0.0275	0.0274	0.0256	0.0256	0.0255	0.0242	0.0241	0.0241	0.0227	0.0226	0.0225
0.26	0.0261	0.0259	0.0258	0.0240	0.0239	0.0238	0.0226	0.0225	0.0224	0.0210	0.0210	0.0209
0.27	0.0247	0.0245	0.0243	0.0226	0.0225	0.0224	0.0212	0.0211	0.0210	0.0196	0.0195	0.0195
0.28	0.0234	0.0232	0.0230	0.0213	0.0212	0.0211	0.0199	0.0198	0.0197	0.0183	0.0182	0.0182
0.29	0.0222	0.0220	0.0219	0.0201	0.0201	0.0200	0.0188	0.0186	0.0186	0.0172	0.0171	0.0170
0.30	0.0212	0.0210	0.0209	0.0191	0.0191	0.0190	0.0177	0.0176	0.0176	0.0162	0.0161	0.0160
0.31	0.0203	0.0201	0.0200	0.0182	0.0182	0.0180	0.0168	0.0167	0.0167	0.0153	0.0152	0.0151
0.32	0.0195	0.0194	0.0192	0.0175	0.0174	0.0173	0.0161	0.0160	0.0159	0.0145	0.0144	0.0144
0.33	0.0189	0.0187	0.0186	0.0168	0.0168	0.0167	0.0155	0.0153	0.0153	0.0139	0.0138	0.0137
0.34	0.0184	0.0182	0.0181	0.0163	0.0163	0.0162	0.0150	0.0148	0.0148	0.0134	0.0133	0.0132
0.35	0.0180	0.0178	0.0177	0.0159	0.0159	0.0158	0.0146	0.0144	0.0144	0.0130	0.0129	0.0128
0.36	0.0177	0.0175	0.0174	0.0157	0.0156	0.0155	0.0143	0.0142	0.0141	0.0127	0.0126	0.0126
0.37	0.0176	0.0174	0.0173	0.0155	0.0155	0.0154	0.0142	0.0140	0.0140	0.0126	0.0125	0.0124
0.38	0.0175	0.0173	0.0172	0.0155	0.0154	0.0153	0.0141	0.0140	0.0139	0.0125	0.0124	0.0124
0.39	0.0176	0.0174	0.0173	0.0156	0.0155	0.0154	0.0142	0.0141	0.0140	0.0126	0.0125	0.0125
0.40	0.0178	0.0176	0.0174	0.0157	0.0156	0.0155	0.0143	0.0142	0.0141	0.0128	0.0127	0.0126
0.41	0.0180	0.0178	0.0177	0.0160	0.0159	0.0158	0.0146	0.0145	0.0144	0.0130	0.0129	0.0129
0.42	0.0184	0.0182	0.0180	0.0163	0.0162	0.0161	0.0150	0.0148	0.0148	0.0134	0.0133	0.0133
0.43	0.0188	0.0186	0.0185	0.0168	0.0167	0.0166	0.0154	0.0153	0.0152	0.0138	0.0138	0.0137
0.44	0.0193	0.0192	0.0190	0.0173	0.0172	0.0171	0.0159	0.0158	0.0158	0.0144	0.0143	0.0142
0.45	0.0200	0.0198	0.0196	0.0179	0.0179	0.0178	0.0166	0.0165	0.0164	0.0150	0.0149	0.0149
0.46	0.0207	0.0205	0.0203	0.0186	0.0186	0.0185	0.0173	0.0172	0.0171	0.0157	0.0156	0.0156
0.47	0.0214	0.0212	0.0211	0.0194	0.0193	0.0192	0.0180	0.0179	0.0178	0.0165	0.0164	0.0163
0.48	0.0223	0.0221	0.0219	0.0202	0.0202	0.0201	0.0189	0.0188	0.0187	0.0173	0.0173	0.0172
0.49	0.0231	0.0230	0.0228	0.0211	0.0211	0.0210	0.0198	0.0197	0.0196	0.0182	0.0182	0.0181
0.50	0.0241	0.0240	0.0238	0.0221	0.0220	0.0220	0.0208	0.0207	0.0206	0.0192	0.0192	0.0191
0.51	0.0252	0.0250	0.0248	0.0231	0.0231	0.0230	0.0218	0.0217	0.0216	0.0203	0.0202	0.0201
0.52	0.0263	0.0261	0.0259	0.0243	0.0242	0.0241	0.0229	0.0228	0.0227	0.0214	0.0213	0.0213
0.53	0.0274	0.0272	0.0271	0.0254	0.0253	0.0252	0.0241	0.0240	0.0239	0.0225	0.0225	0.0224
0.54	0.0285	0.0283	0.0282	0.0265	0.0265	0.0264	0.0252	0.0251	0.0250	0.0237	0.0236	0.0236
0.55	0.0297	0.0295	0.0294	0.0278	0.0277	0.0276	0.0264	0.0263	0.0263	0.0249	0.0248	0.0248
0.56	0.0310	0.0308	0.0306	0.0290	0.0289	0.0288	0.0277	0.0276	0.0275	0.0262	0.0261	0.0260
0.57	0.0323	0.0321	0.0319	0.0303	0.0302	0.0301	0.0290	0.0289	0.0288	0.0275	0.0274	0.0274
0.58	0.0335	0.0334	0.0332	0.0316	0.0315	0.0314	0.0303	0.0302	0.0301	0.0288	0.0287	0.0287
0.59	0.0349	0.0347	0.0346	0.0330	0.0329	0.0328	0.0317	0.0316	0.0315	0.0302	0.0301	0.0300
0.60	0.0363	0.0361	0.0359	0.0343	0.0342	0.0342	0.0330	0.0329	0.0328	0.0315	0.0315	0.0314
0.61	0.0376	0.0374	0.0373	0.0356	0.0356	0.0355	0.0343	0.0342	0.0342	0.0329	0.0328	0.0327
0.62	0.0389	0.0388	0.0386	0.0370	0.0370	0.0369	0.0357	0.0356	0.0356	0.0343	0.0342	0.0341
0.63	0.0403	0.0401	0.0400	0.0384	0.0383	0.0382	0.0371	0.0370	0.0369	0.0356	0.0356	0.0355
0.64	0.0416	0.0415	0.0413	0.0397	0.0397	0.0396	0.0384	0.0384	0.0383	0.0370	0.0369	0.0369
0.65	0.0430	0.0428	0.0427	0.0411	0.0410	0.0409	0.0398	0.0397	0.0397	0.0384	0.0383	0.0383
0.66	0.0443	0.0441	0.0440	0.0424	0.0423	0.0422	0.0411	0.0410	0.0410	0.0397	0.0396	0.0396
0.67	0.0456	0.0454	0.0452	0.0437	0.0436	0.0435	0.0425	0.0424	0.0423	0.0410	0.0410	0.0409
0.68	0.0468	0.0467	0.0465	0.0450	0.0449	0.0448	0.0438	0.0436	0.0436	0.0423	0.0423	0.0422
0.69	0.0480	0.0479	0.0477	0.0462	0.0461	0.0460	0.0450	0.0449	0.0448	0.0436	0.0435	0.0435
0.70	0.0492	0.0491	0.0489	0.0474	0.0473	0.0472	0.0462	0.0461	0.0460	0.0448	0.0447	0.0447
0.71	0.0503	0.0501	0.0500	0.0485	0.0484	0.0484	0.0473	0.0472	0.0471	0.0459	0.0459	0.0458
0.72	0.0514	0.0512	0.0511	0.0496	0.0495	0.0495	0.0484	0.0483	0.0483	0.0471	0.0470	0.0469
0.73	0.0524	0.0523	0.0522	0.0507	0.0506	0.0505	0.0495	0.0494	0.0493	0.0482	0.0481	0.0480
0.74	0.0534	0.0532	0.0531	0.0517	0.0516	0.0515	0.0505	0.0504	0.0503	0.0492	0.0491	0.0490
0.75	0.0542	0.0540	0.0540	0.0525	0.0522	0.0523	0.0513	0.0512	0.0512	0.0500	0.0499	0.0499

TABLE 2

Pipe Diameter Factors, F_d — Pipe Taps

Internal diameter of pipe in inches, D

β	2			3				4				6
	1.689	1.939	2.067	2.300	2.626	2.900	3.068	3.152	3.438	3.826	4.026	4.897
0.10	1.0140	1.0141	1.0134	1.0118	1.0090	1.0067	1.0054	1.0048	1.0030	1.0009	1.0000	0.9972
0.11	1.0139	1.0136	1.0129	1.0112	1.0083	1.0062	1.0049	1.0044	1.0027	1.0008		0.9977
0.12	1.0136	1.0130	1.0122	1.0103	1.0076	1.0055	1.0044	1.0039	1.0023	1.0007		0.9981
0.13	1.0131	1.0122	1.0114	1.0095	1.0068	1.0049	1.0038	1.0034	1.0020	1.0006		0.9986
0.14	1.0125	1.0114	1.0104	1.0085	1.0060	1.0042	1.0032	1.0028	1.0016	1.0004		0.9990
0.15	1.0117	1.0104	1.0094	1.0075	1.0051	1.0035	1.0026	1.0023	1.0013	1.0003	1.0000	0.9994
0.16	1.0108	1.0093	1.0083	1.0065	1.0042	1.0028	1.0020	1.0017	1.0009	1.0002		0.9997
0.17	1.0097	1.0082	1.0072	1.0054	1.0033	1.0021	1.0015	1.0012	1.0006	1.0002		1.0000
0.18	1.0087	1.0070	1.0060	1.0044	1.0025	1.0014	1.0009	1.0007	1.0003	1.0000		1.0002
0.19	1.0076	1.0059	1.0049	1.0033	1.0017	1.0008	1.0004	1.0003	1.0000	0.9999		1.0003
0.20	1.0065	1.0048	1.0039	1.0024	1.0010	1.0003	1.0001	1.0000	0.9999	0.9999	1.0000	1.0003
0.21	1.0056	1.0038	1.0030	1.0017	1.0005	1.0000	0.9998	0.9998	0.9998	0.9999		1.0002
0.22	1.0047	1.0030	1.0022	1.0011	1.0001	0.9998	0.9997	0.9997	0.9998	0.9999		1.0002
0.23	1.0040	1.0023	1.0016	1.0006	0.9999	0.9997	0.9998	0.9998	0.9998	1.0000		1.0002
0.24	1.0033	1.0017	1.0011	1.0003	0.9998	0.9997	0.9998	0.9998	0.9999	1.0000		1.0002
0.25	1.0027	1.0013	1.0007	1.0000	0.9998	0.9998	0.9998	0.9998	0.9999	1.0000	1.0000	1.0001
0.26	1.0023	1.0009	1.0004	0.9999	0.9998	0.9998	0.9999	0.9999	0.9999	1.0000		1.0001
0.27	1.0019	1.0007	1.0003	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	1.0000		1.0001
0.28	1.0016	1.0005	1.0002	1.0000	0.9999	0.9999	0.9999	0.9999	1.0000	1.0000		1.0001
0.29	1.0013	1.0003	1.0002	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000		1.0001
0.30	1.0012	1.0004	1.0002	1.0001	1.0001	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.31	1.0011	1.0004	1.0003	1.0002	1.0001	1.0001	1.0000	1.0000	1.0000	1.0000		1.0000
0.32	1.0010	1.0005	1.0004	1.0003	1.0002	1.0001	1.0001	1.0001	1.0000	1.0000		1.0000
0.33	1.0010	1.0006	1.0005	1.0004	1.0002	1.0002	1.0001	1.0001	1.0001	1.0000		1.0000
0.34	1.0011	1.0008	1.0006	1.0005	1.0003	1.0002	1.0002	1.0001	1.0001	1.0000		0.9999
0.35	1.0012	1.0009	1.0008	1.0006	1.0004	1.0003	1.0002	1.0002	1.0001	1.0000	1.0000	0.9999
0.36	1.0014	1.0010	1.0009	1.0007	1.0004	1.0003	1.0002	1.0002	1.0001	1.0000		0.9999
0.37	1.0015	1.0012	1.0010	1.0008	1.0005	1.0004	1.0003	1.0002	1.0001	1.0000		0.9999
0.38	1.0017	1.0013	1.0011	1.0009	1.0006	1.0004	1.0003	1.0003	1.0002	1.0001		0.9998
0.39	1.0019	1.0014	1.0012	1.0009	1.0007	1.0005	1.0004	1.0003	1.0002	1.0001		0.9998
0.40	1.0020	1.0016	1.0013	1.0010	1.0007	1.0005	1.0004	1.0004	1.0002	1.0001	1.0000	0.9998
0.41	1.0022	1.0017	1.0015	1.0011	1.0008	1.0006	1.0005	1.0004	1.0002	1.0001		0.9998
0.42	1.0024	1.0018	1.0016	1.0012	1.0009	1.0006	1.0005	1.0004	1.0003	1.0001		0.9997
0.43	1.0026	1.0020	1.0017	1.0013	1.0009	1.0007	1.0005	1.0005	1.0003	1.0001		0.9997
0.44	1.0027	1.0021	1.0018	1.0014	1.0010	1.0007	1.0006	1.0005	1.0003	1.0001		0.9997
0.45	1.0029	1.0022	1.0020	1.0015	1.0011	1.0008	1.0006	1.0006	1.0003	1.0001	1.0000	0.9997
0.46	1.0031	1.0024	1.0021	1.0016	1.0012	1.0008	1.0007	1.0006	1.0004	1.0001		0.9996
0.47	1.0032	1.0025	1.0022	1.0017	1.0012	1.0009	1.0007	1.0006	1.0004	1.0001		0.9996
0.48	1.0034	1.0026	1.0023	1.0018	1.0013	1.0009	1.0008	1.0007	1.0004	1.0001		0.9996
0.49	1.0036	1.0028	1.0024	1.0019	1.0014	1.0010	1.0008	1.0007	1.0004	1.0001		0.9995
0.50	1.0037	1.0029	1.0026	1.0020	1.0014	1.0010	1.0008	1.0007	1.0005	1.0001	1.0000	0.9995
0.51	1.0039	1.0030	1.0027	1.0021	1.0015	1.0011	1.0009	1.0008	1.0005	1.0001		0.9995
0.52	1.0041	1.0032	1.0028	1.0022	1.0016	1.0012	1.0009	1.0008	1.0005	1.0002		0.9995
0.53	1.0042	1.0033	1.0029	1.0023	1.0016	1.0012	1.0010	1.0009	1.0005	1.0002		0.9994
0.54	1.0044	1.0034	1.0030	1.0024	1.0017	1.0013	1.0010	1.0009	1.0006	1.0002		0.9994
0.55	1.0046	1.0036	1.0032	1.0025	1.0018	1.0013	1.0011	1.0009	1.0006	1.0002	1.0000	0.9994
0.56	1.0048	1.0037	1.0033	1.0026	1.0019	1.0014	1.0011	1.0010	1.0006	1.0002		0.9993
0.57	1.0050	1.0039	1.0035	1.0028	1.0020	1.0015	1.0012	1.0010	1.0006	1.0002		0.9993
0.58	1.0052	1.0041	1.0036	1.0029	1.0021	1.0015	1.0012	1.0011	1.0007	1.0002		0.9993
0.59	1.0054	1.0043	1.0038	1.0030	1.0022	1.0016	1.0013	1.0011	1.0007	1.0002		0.9992
0.60	1.0056	1.0044	1.0039	1.0031	1.0023	1.0017	1.0014	1.0012	1.0007	1.0002	1.0000	0.9992
0.61	1.0059	1.0046	1.0041	1.0033	1.0024	1.0017	1.0014	1.0013	1.0008	1.0002		0.9992
0.62	1.0061	1.0048	1.0043	1.0034	1.0025	1.0018	1.0015	1.0013	1.0008	1.0003		0.9991
0.63	1.0064	1.0050	1.0045	1.0036	1.0026	1.0019	1.0016	1.0014	1.0009	1.0003		0.9991
0.64	1.0066	1.0052	1.0047	1.0037	1.0027	1.0020	1.0016	1.0014	1.0009	1.0003		0.9990
0.65	1.0069	1.0055	1.0049	1.0039	1.0028	1.0021	1.0017	1.0015	1.0009	1.0003	1.0000	0.9990
0.66	1.0072	1.0057	1.0051	1.0041	1.0030	1.0022	1.0018	1.0016	1.0010	1.0003		0.9989
0.67	1.0075	1.0059	1.0053	1.0043	1.0031	1.0023	1.0019	1.0017	1.0010	1.0003		0.9989
0.68	1.0078	1.0062	1.0055	1.0044	1.0032	1.0024	1.0019	1.0017	1.0011	1.0003		0.9988
0.69	1.0081	1.0064	1.0057	1.0046	1.0034	1.0025	1.0020	1.0018	1.0011	1.0003		0.9988
0.70	1.0084	1.0067	1.0060	1.0048	1.0035	1.0026	1.0021	1.0019	1.0012	1.0004	1.0000	0.9987
0.71	1.0090	1.0071	1.0064	1.0051	1.0037	1.0028	1.0022	1.0020	1.0012	1.0004		0.9986
0.72	1.0105	1.0083	1.0073	1.0059	1.0042	1.0031	1.0025	1.0023	1.0014	1.0004		0.9985
0.73	1.0134	1.0104	1.0091	1.0074	1.0051	1.0037	1.0030	1.0029	1.0016	1.0005		0.9983
0.74	1.0180	1.0136	1.0119	1.0097	1.0065	1.0047	1.0037	1.0038	1.0020	1.0006		0.9979
0.75	1.0243	1.0182	1.0157	1.0129	1.0084	1.0060	1.0048	1.0050	1.0026	1.0008		0.9974

Internal diameter of pipe in inches, D

β	6			8			10			12		
	5.189	5.761	6.065	7.625	7.981	8.071	9.564	10.020	10.136	11.376	11.938	12.090
0.10	0.9966	0.9957	0.9953	0.9943	0.9342	0.9942	0.9940	0.9939	0.9939	0.9941	0.9940	0.9940
0.11	0.9972	0.9965	0.9362	0.9956	0.9956	0.9956	0.9956	0.9956	0.9956	0.9957	0.9958	0.9958
0.12	0.9977	0.9973	0.9971	0.9969	0.9969	0.9969	0.9971	0.9972	0.9972	0.9973	0.9974	0.9974
0.13	0.9983	0.9979	0.9980	0.9981	0.9981	0.9981	0.9984	0.9984	0.9985	0.9986	0.9987	0.9987
0.14	0.9989	0.9988	0.9988	0.9991	0.9991	0.9992	0.9994	0.9995	0.9995	0.9996	0.9997	0.9997
0.15	0.9994	0.9994	0.9995	0.9998	0.9999	0.9999	1.0001	1.0002	1.0002	1.0004	1.0004	1.0004
0.16	0.9998	1.0000	1.0000	1.0004	1.0004	1.0004	1.0007	1.0007	1.0007	1.0009	1.0009	1.0009
0.17	1.0001	1.0003	1.0004	1.0009	1.0008	1.0008	1.0010	1.0010	1.0010	1.0012	1.0012	1.0012
0.18	1.0003	1.0005	1.0005	1.0008	1.0009	1.0009	1.0011	1.0011	1.0011	1.0013	1.0013	1.0013
0.19	1.0004	1.0005	1.0006	1.0008	1.0009	1.0009	1.0011	1.0011	1.0011	1.0013	1.0013	1.0013
0.20	1.0003	1.0005	1.0005	1.0008	1.0008	1.0008	1.0010	1.0011	1.0011	1.0012	1.0012	1.0012
0.21	1.0003	1.0004	1.0005	1.0007	1.0008	1.0008	1.0009	1.0010	1.0010	1.0011	1.0011	1.0011
0.22	1.0003	1.0004	1.0004	1.0007	1.0007	1.0007	1.0009	1.0009	1.0009	1.0010	1.0011	1.0011
0.23	1.0002	1.0003	1.0004	1.0006	1.0006	1.0006	1.0008	1.0008	1.0008	1.0009	1.0010	1.0010
0.24	1.0002	1.0003	1.0003	1.0005	1.0006	1.0006	1.0007	1.0008	1.0008	1.0008	1.0009	1.0009
0.25	1.0002	1.0003	1.0003	1.0005	1.0005	1.0005	1.0006	1.0007	1.0007	1.0008	1.0008	1.0008
0.26	1.0002	1.0002	1.0003	1.0004	1.0004	1.0005	1.0006	1.0006	1.0006	1.0007	1.0007	1.0007
0.27	1.0001	1.0002	1.0002	1.0004	1.0004	1.0004	1.0005	1.0005	1.0005	1.0006	1.0006	1.0006
0.28	1.0001	1.0001	1.0002	1.0003	1.0003	1.0003	1.0004	1.0004	1.0004	1.0005	1.0005	1.0005
0.29	1.0001	1.0001	1.0001	1.0002	1.0003	1.0003	1.0003	1.0004	1.0004	1.0004	1.0004	1.0005
0.30	1.0000	1.0001	1.0001	1.0002	1.0002	1.0002	1.0003	1.0003	1.0003	1.0003	1.0004	1.0004
0.31	1.0000	1.0000	1.0000	1.0001	1.0001	1.0001	1.0002	1.0002	1.0002	1.0003	1.0003	1.0003
0.32	1.0000	1.0000	1.0000	1.0000	1.0001	1.0001	1.0001	1.0001	1.0001	1.0002	1.0002	1.0002
0.33	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0001	1.0001	1.0001
0.34	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	1.0000	1.0000	1.0000	1.0000	1.0000
0.35	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
0.36	0.9999	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998
0.37	0.9998	0.9998	0.9998	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997
0.38	0.9998	0.9997	0.9997	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996
0.39	0.9998	0.9997	0.9997	0.9996	0.9996	0.9996	0.9995	0.9995	0.9995	0.9995	0.9995	0.9995
0.40	0.9998	0.9997	0.9996	0.9995	0.9995	0.9995	0.9994	0.9994	0.9994	0.9994	0.9994	0.9994
0.41	0.9997	0.9996	0.9995	0.9994	0.9994	0.9994	0.9993	0.9993	0.9993	0.9993	0.9993	0.9993
0.42	0.9997	0.9996	0.9995	0.9994	0.9993	0.9993	0.9992	0.9992	0.9992	0.9992	0.9992	0.9992
0.43	0.9995	9.9995	9.9995	0.9993	0.9993	0.9992	0.9992	0.9991	0.9991	0.9991	0.9991	0.9991
0.44	0.9996	0.9995	0.9994	0.9992	0.9992	0.9992	0.9991	0.9990	0.9990	0.9990	0.9989	0.9989
0.45	0.9996	0.9994	0.9994	0.9991	0.9991	0.9991	0.9990	0.9989	0.9989	0.9989	0.9988	0.9988
0.46	0.9995	0.9994	0.9993	0.9991	0.9990	0.9990	0.9989	0.9988	0.9988	0.9987	0.9987	0.9987
0.47	0.9995	0.9993	0.9993	0.9990	0.9989	0.9989	0.9988	0.9987	0.9987	0.9986	0.9986	0.9986
0.48	0.9995	0.9993	0.9992	0.9989	0.9988	0.9988	0.9987	0.9986	0.9986	0.9985	0.9985	0.9985
0.49	0.9994	0.9992	0.9992	0.9988	0.9988	0.9987	0.9985	0.9985	0.9985	0.9984	0.9983	0.9983
0.50	0.9994	0.9992	0.9991	0.9987	0.9987	0.9987	0.9984	0.9984	0.9984	0.9983	0.9982	0.9982
0.51	0.9994	0.9991	0.9990	0.9987	0.9986	0.9986	0.9983	0.9983	0.9983	0.9982	0.9981	0.9981
0.52	0.9993	0.9991	0.9990	0.9986	0.9985	0.9985	0.9982	0.9982	0.9982	0.9980	0.9980	0.9980
0.53	0.9993	0.9990	0.9989	0.9985	0.9984	0.9984	0.9981	0.9981	0.9981	0.9979	0.9978	0.9978
0.54	0.9993	0.9990	0.9989	0.9984	0.9983	0.9983	0.9980	0.9979	0.9979	0.9978	0.9977	0.9977
0.55	0.9992	0.9989	0.9988	0.9983	0.9982	0.9982	0.9979	0.9978	0.9978	0.9976	0.9976	0.9975
0.56	0.9992	0.9989	0.9987	0.9982	0.9981	0.9981	0.9978	0.9977	0.9977	0.9975	0.9974	0.9974
0.57	0.9991	0.9988	0.9987	0.9981	0.9980	0.9980	0.9976	0.9975	0.9975	0.9973	0.9973	0.9972
0.58	0.9991	0.9987	0.9986	0.9980	0.9979	0.9979	0.9974	0.9974	0.9974	0.9972	0.9971	0.9971
0.59	0.9990	0.9987	0.9985	0.9979	0.9978	0.9977	0.9973	0.9973	0.9972	0.9970	0.9969	0.9969
0.60	0.9990	0.9986	0.9984	0.9978	0.9976	0.9976	0.9972	0.9971	0.9971	0.9968	0.9967	0.9967
0.61	0.9989	0.9985	0.9984	0.9976	0.9975	0.9975	0.9970	0.9969	0.9969	0.9966	0.9965	0.9965
0.62	0.9989	0.9985	0.9983	0.9975	0.9974	0.9973	0.9969	0.9968	0.9967	0.9965	0.9963	0.9963
0.63	0.9988	0.9984	0.9982	0.9974	0.9972	0.9972	0.9967	0.9966	0.9966	0.9963	0.9961	0.9961
0.64	0.9988	0.9983	0.9981	0.9972	0.9971	0.9971	0.9965	0.9964	0.9964	0.9961	0.9959	0.9959
0.65	0.9987	0.9982	0.9980	0.9971	0.9969	0.9969	0.9964	0.9962	0.9962	0.9958	0.9957	0.9957
0.66	0.9986	0.9981	0.9979	0.9970	0.9968	0.9967	0.9962	0.9960	0.9960	0.9956	0.9955	0.9955
0.67	0.9986	0.9980	0.9978	0.9968	0.9966	0.9966	0.9960	0.9958	0.9958	0.9954	0.9953	0.9952
0.68	0.9985	0.9979	0.9977	0.9967	0.9965	0.9964	0.9958	0.9956	0.9956	0.9952	0.9950	0.9950
0.69	0.9984	0.9979	0.9976	0.9965	0.9963	0.9962	0.9956	0.9954	0.9953	0.9949	0.9948	0.9947
0.70	0.9984	0.9978	0.9975	0.9963	0.9961	0.9961	0.9954	0.9952	0.9951	0.9947	0.9945	0.9945
0.71	0.9983	0.9976	0.9973	0.9961	0.9959	0.9958	0.9951	0.9949	0.9948	0.9944	0.9942	0.9942
0.72	0.9981	0.9974	0.9971	0.9958	0.9955	0.9955	0.9946	0.9944	0.9944	0.9939	0.9937	0.9937
0.73	0.9978	0.9970	0.9966	0.9952	0.9949	0.9949	0.9940	0.9937	0.9937	0.9932	0.9930	0.9923
0.74	0.9974	0.9964	0.9960	0.9944	0.9941	0.9940	0.9930	0.9928	0.9927	0.9921	0.9919	0.9918
0.75	0.9968	0.9957	0.9952	0.9933	0.9929	0.9928	0.9917	0.9914	0.9914	0.9907	0.9905	0.9904

Internal diameter of pipe in inches, D

β	16			20			24			30		
	14.688	15.000	15.250	18.814	19.000	19.250	22.626	23.000	23.250	28.628	29.000	29.250
0.10	0.9942	0.9942	0.9942	0.9945	0.9945	0.9945	0.9946	0.9946	0.9947	0.9948	0.9948	0.9949
0.11	0.9961	0.9951	0.9961	0.9963	0.9963	0.9964	0.9965	0.9965	0.9965	0.9967	0.9967	0.9967
0.12	0.9976	0.9977	0.9977	0.9979	0.9979	0.9979	0.9981	0.9981	0.9981	0.9983	0.9983	0.9983
0.13	0.9989	0.9989	0.9989	0.9992	0.9992	0.9992	0.9993	0.9994	0.9994	0.9995	0.9995	0.9995
0.14	0.9999	0.9999	0.9999	1.0002	1.0002	1.0002	1.0003	1.0003	1.0003	1.0005	1.0005	1.0005
0.15	1.0006	1.0007	1.0006	1.0009	1.0009	1.0009	1.0010	1.0010	1.0011	1.0012	1.0012	1.0012
0.16	1.0011	1.0011	1.0011	1.0014	1.0014	1.0014	1.0015	1.0015	1.0015	1.0017	1.0017	1.0017
0.17	1.0014	1.0014	1.0014	1.0016	1.0016	1.0017	1.0018	1.0018	1.0018	1.0020	1.0020	1.0020
0.18	1.0015	1.0015	1.0015	1.0017	1.0017	1.0018	1.0019	1.0019	1.0019	1.0020	1.0021	1.0021
0.19	1.0015	1.0015	1.0015	1.0017	1.0017	1.0017	1.0018	1.0019	1.0019	1.0020	1.0020	1.0020
0.20	1.0014	1.0014	1.0014	1.0016	1.0016	1.0016	1.0017	1.0018	1.0018	1.0019	1.0019	1.0019
0.21	1.0013	1.0013	1.0013	1.0015	1.0015	1.0015	1.0016	1.0016	1.0017	1.0018	1.0018	1.0018
0.22	1.0012	1.0012	1.0012	1.0014	1.0014	1.0014	1.0015	1.0015	1.0015	1.0017	1.0017	1.0017
0.23	1.0011	1.0011	1.0011	1.0013	1.0013	1.0013	1.0014	1.0014	1.0014	1.0016	1.0016	1.0016
0.24	1.0010	1.0010	1.0010	1.0012	1.0012	1.0012	1.0013	1.0013	1.0013	1.0014	1.0015	1.0015
0.25	1.0009	1.0010	1.0009	1.0011	1.0011	1.0011	1.0012	1.0012	1.0012	1.0013	1.0013	1.0013
0.26	1.0008	1.0009	1.0009	1.0010	1.0010	1.0010	1.0011	1.0011	1.0011	1.0012	1.0012	1.0012
0.27	1.0008	1.0008	1.0008	1.0009	1.0009	1.0009	1.0010	1.0010	1.0010	1.0011	1.0011	1.0011
0.28	1.0005	1.0007	1.0007	1.0008	1.0008	1.0008	1.0009	1.0009	1.0009	1.0010	1.0010	1.0010
0.29	1.0006	1.0006	1.0006	1.0007	1.0007	1.0007	1.0008	1.0008	1.0008	1.0009	1.0009	1.0009
0.30	1.0005	1.0005	1.0005	1.0006	1.0006	1.0006	1.0006	1.0007	1.0007	1.0007	1.0008	1.0008
0.31	1.0004	1.0004	1.0004	1.0005	1.0005	1.0005	1.0005	1.0005	1.0005	1.0006	1.0006	1.0006
0.32	1.0003	1.0003	1.0003	1.0003	1.0003	1.0004	1.0004	1.0004	1.0004	1.0005	1.0005	1.0005
0.33	1.0001	1.0002	1.0002	1.0002	1.0002	1.0002	1.0003	1.0003	1.0003	1.0004	1.0004	1.0004
0.34	1.0000	1.0001	1.0000	1.0001	1.0001	1.0001	1.0002	1.0002	1.0002	1.0002	1.0002	1.0002
0.35	0.9999	0.9999	0.9999	1.0000	1.0000	1.0000	1.0000	1.0001	1.0001	1.0001	1.0001	1.0001
0.36	0.9998	0.9998	0.9998	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	1.0000	1.0000	1.0000
0.37	0.9997	0.9997	0.9997	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998
0.38	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997
0.39	0.9995	0.9995	0.9995	0.9995	0.9995	0.9995	0.9995	0.9995	0.9995	0.9996	0.9996	0.9996
0.40	0.9994	0.9994	0.9994	0.9994	0.9994	0.9994	0.9994	0.9994	0.9994	0.9994	0.9994	0.9994
0.41	0.9993	0.9993	0.9992	0.9992	0.9992	0.9992	0.9992	0.9992	0.9992	0.9992	0.9993	0.9993
0.42	0.9991	0.9991	0.9991	0.9991	0.9991	0.9991	0.9991	0.9991	0.9991	0.9991	0.9991	0.9991
0.43	0.9990	0.9990	0.9990	0.9990	0.9990	0.9990	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989
0.44	0.9989	0.9989	0.9989	0.9988	0.9988	0.9988	0.9988	0.9988	0.9988	0.9988	0.9988	0.9988
0.45	0.9987	0.9987	0.9987	0.9987	0.9987	0.9987	0.9986	0.9986	0.9986	0.9986	0.9986	0.9986
0.46	0.9986	0.9986	0.9986	0.9985	0.9985	0.9985	0.9985	0.9985	0.9985	0.9984	0.9984	0.9984
0.47	0.9985	0.9985	0.9985	0.9984	0.9984	0.9984	0.9983	0.9983	0.9983	0.9983	0.9983	0.9982
0.48	0.9983	0.9983	0.9983	0.9982	0.9982	0.9982	0.9981	0.9981	0.9981	0.9981	0.9981	0.9981
0.49	0.9982	0.9982	0.9982	0.9981	0.9981	0.9980	0.9980	0.9980	0.9980	0.9979	0.9979	0.9979
0.50	0.9981	0.9980	0.9980	0.9979	0.9979	0.9979	0.9978	0.9978	0.9978	0.9977	0.9977	0.9977
0.51	0.9979	0.9979	0.9979	0.9977	0.9977	0.9977	0.9976	0.9976	0.9976	0.9975	0.9975	0.9975
0.52	0.9978	0.9978	0.9977	0.9976	0.9976	0.9976	0.9975	0.9975	0.9975	0.9973	0.9973	0.9973
0.53	0.9976	0.9976	0.9976	0.9974	0.9974	0.9974	0.9973	0.9973	0.9973	0.9971	0.9971	0.9971
0.54	0.9975	0.9974	0.9974	0.9972	0.9972	0.9972	0.9971	0.9971	0.9971	0.9969	0 69	0.9969
0.55	0.9973	0.9973	0.9973	0.9970	0.9970	0.9970	0.9969	0.9969	0.9969	0.9967	0.9967	0.9967
0.56	0.9971	0.9971	0.9971	0.9969	0.9968	0.9968	0.9967	0.9967	0.9967	0.9965	0.9965	0.9965
0.57	0.9969	0.9969	0.9969	0.9966	0.9966	0.9966	0.9965	0.9964	0.9964	0.9962	0.9962	0.9962
0.58	0.9968	0.9967	0.9967	0.9964	0.9964	0.9964	0.9962	0.9962	0.9962	0.9960	0.9960	0.9960
0.59	0.9966	0.9965	0.9965	0.9962	0.9962	0.9962	0.9960	0.9960	0.9960	0.9957	0.9957	0.9957
0.60	0.9964	0.9963	0.9963	0.9960	0.9960	0.9959	0.9957	0.9957	0.9957	0.9955	0.9955	0.9954
0.61	0.9961	0.9961	0.9961	0.9957	0.9957	0.9957	0.9955	0.9954	0.9954	0.9952	0.9952	0.9952
0.62	0.9959	0.9959	0.9958	0.9955	0.9955	0.9954	0.9952	0.9952	0.9952	0.9949	0.9949	0.9949
0.63	0.9957	0.9956	0.9956	0.9952	0.9952	0.9952	0.9949	0.9949	0.9949	0.9946	0.9946	0.9946
0.64	0.9954	0.9954	0.9954	0.9949	0.9949	0.9949	0.9946	0.9946	0.9946	0.9943	0.9942	0.9942
0.65	0.9952	0.9952	0.9951	0.9947	0.9947	0.9946	0.9943	0.9943	0.9943	0.9939	0.9939	0.9939
0.66	0.9949	0.9949	0.9949	0.9944	0.9944	0.9943	0.9940	0.9940	0.9940	0.9936	0.9936	0.9936
0.67	0.9947	0.9946	0.9946	0.9941	0.9941	0.9940	0.9937	0.9937	0.9936	0.9933	0.9932	0.9932
0.68	0.9944	0.9944	0.9943	0.9938	0.9938	0.9937	0.9934	0.9933	0.9933	0.9929	0.9929	0.9929
0.69	0.9941	0.9941	0.9940	0.9935	0.9934	0.9934	0.9930	0.9930	0.9930	0.9925	0.9925	0.9925
0.70	0.9938	0.9938	0.9937	0.9931	0.9931	0.9931	0.9927	0.9926	0.9926	0.9921	0.9921	0.9921
0.71	0.9935	0.9934	0.9934	0.9927	0.9927	0.9927	0.9923	0.9922	0.9922	0.9917	0.9917	0.9917
0.72	0.9929	0.9929	0.9928	0.9922	0.9921	0.9921	0.9916	0.9916	0.9916	0.9910	0.9908	0.9910
0.73	0.9921	0.9921	0.9920	0.9913	0.9912	0.9912	0.9907	0.9907	0.9906	0.9901	0.9901	0.9900
0.74	0.9910	0.9909	0.9908	0.9901	0.9900	0.9900	0.9895	0.9894	0.9894	0.9888	0.9888	0.9888
0.75	0.9895	0.9894	0.9893	0.9885	0.9885	0.9884	0.9879	0.9878	0.9878	0.9872	0.9871	0.9871

TABLE 3

Values of F_x — Flange Taps

β	0	1	2	3	4	5	6	7	8	9
0.10	2.014	2.054	2.095	2.136	2.177	2.219	2.261	2.304	2.347	2.390
0.11	2.434	2.478	2.523	2.568	2.613	2.659	2.705	2.752	2.799	2.846
0.12	2.894	2.942	2.991	3.040	3.089	3.139	3.189	3.240	3.291	3.342
0.13	3.394	3.446	3.499	3.552	3.606	3.659	3.714	3.769	3.824	3.879
0.14	3.935	3.991	4.048	4.105	4.163	4.221	4.279	4.338	4.397	4.457
0.15	4.517	4.577	4.638	4.699	4.761	4.823	4.886	4.949	5.012	5.076
0.16	5.140	5.205	5.270	5.335	5.401	5.467	5.534	5.601	5.668	5.736
0.17	5.805	5.873	5.942	6.012	6.082	6.152	6.223	6.295	6.366	6.438
0.18	6.511	6.584	6.657	6.731	6.805	6.880	6.955	7.030	7.106	7.183
0.19	7.259	7.336	7.414	7.492	7.570	7.649	7.728	7.808	7.888	7.968
0.20	8.049	8.131	8.212	8.294	8.377	8.460	8.543	8.627	8.711	8.796
0.21	8.881	8.966	9.052	9.139	9.225	9.312	9.400	9.488	9.576	9.665
0.22	9.754	9.844	9.934	10.024	10.115	10.207	10.298	10.390	10.483	10.576
0.23	10.669	10.763	10.857	10.952	11.047	11.143	11.239	11.335	11.432	11.529
0.24	11.627	11.725	11.823	11.922	12.021	12.121	12.221	12.322	12.423	12.524
0.25	12.626	12.728	12.831	12.934	13.038	13.141	13.246	13.351	13.456	13.562
0.26	13.668	13.774	13.881	13.989	14.097	14.205	14.313	14.422	14.532	14.642
0.27	14.752	14.863	14.974	15.086	15.198	15.311	15.423	15.537	15.651	15.765
0.28	15.880	15.995	16.110	16.226	16.343	16.460	16.577	16.695	16.813	16.931
0.29	17.050	17.170	17.290	17.410	17.531	17.652	17.774	17.896	18.018	18.141
0.30	18.265	18.389	18.513	18.638	18.763	18.889	19.015	19.141	19.268	19.395
0.31	19.523	19.651	19.780	19.909	20.039	20.169	20.300	20.431	20.562	20.694
0.32	20.826	20.959	21.092	21.226	21.360	21.494	21.629	21.765	21.901	22.037
0.33	22.174	22.311	22.449	22.587	22.726	22.865	23.004	23.144	23.285	23.426
0.34	23.567	23.709	23.851	23.994	24.137	24.281	24.425	24.570	24.715	24.860
0.35	25.006	25.153	25.300	25.447	25.595	25.744	25.892	26.042	26.191	26.342
0.36	26.492	26.644	26.795	26.947	27.100	27.253	27.407	27.560	27.715	27.870
0.37	28.025	28.181	28.338	28.493	28.652	28.810	28.968	29.127	29.287	29.446
0.38	29.607	29.767	29.929	30.091	30.253	30.416	30.579	30.743	30.907	31.071
0.39	31.237	31.402	31.568	31.735	31.902	32.070	32.238	32.407	32.576	32.746
0.40	32.916	33.087	33.258	33.430	33.602	33.775	33.948	34.122	34.297	34.471
0.41	34.647	34.823	34.999	35.176	35.353	35.531	35.710	35.889	36.068	36.248
0.42	36.429	36.610	36.791	36.974	37.156	37.339	37.523	37.707	37.892	38.077
0.43	38.263	38.450	38.636	38.824	39.012	39.201	39.390	39.579	39.769	39.960
0.44	40.151	40.343	40.536	40.729	40.922	41.116	41.310	41.506	41.702	41.898
0.45	42.095	42.292	42.490	42.689	42.888	43.087	43.288	43.488	43.690	43.892
0.46	44.094	44.298	44.501	44.706	44.911	45.116	45.322	45.528	45.736	45.943
0.47	46.152	46.361	46.570	46.780	46.991	47.203	47.415	47.627	47.840	48.054
0.48	48.268	48.484	48.699	48.915	49.132	49.349	49.567	49.786	50.005	50.225
0.49	50.446	50.667	50.888	51.111	51.334	51.557	51.782	52.007	52.232	52.458
0.50	52.685	52.912	53.140	53.369	53.598	53.828	54.058	54.290	54.521	54.754
0.51	54.987	55.221	55.456	55.691	55.927	56.164	56.401	56.639	56.878	57.117
0.52	57.357	57.597	57.839	58.081	58.324	58.567	58.811	59.056	59.302	59.548
0.53	59.795	60.043	60.291	60.540	60.790	61.041	61.292	61.544	61.797	62.051
0.54	62.305	62.560	62.815	63.072	63.329	63.587	63.846	64.105	64.365	64.626
0.55	64.888	65.150	65.414	65.678	65.943	66.208	66.475	66.742	67.010	67.278
0.56	67.548	67.818	68.089	68.361	68.634	68.907	69.181	69.457	69.732	70.009
0.57	70.286	70.565	70.844	71.124	71.405	71.686	71.969	72.252	72.537	72.821
0.58	73.107	73.394	73.682	73.970	74.259	74.549	74.840	75.132	75.425	75.718
0.59	76.013	76.308	76.604	76.901	77.199	77.498	77.798	78.098	78.400	78.702
0.60	79.006	79.310	79.615	79.922	80.229	80.537	80.846	81.156	81.467	81.778
0.61	82.091	82.404	82.719	83.035	83.351	83.669	83.987	84.306	84.627	84.948
0.62	85.271	85.594	85.919	86.244	86.571	86.898	87.226	87.555	87.886	88.217
0.63	88.550	88.884	89.218	89.553	89.890	90.227	90.566	90.906	91.246	91.588
0.64	91.931	92.275	92.620	92.966	93.313	93.661	94.010	94.361	94.712	95.065
0.65	95.419	95.773	96.129	96.486	96.844	97.204	97.564	97.926	98.288	98.652
0.66	99.017	99.383	99.750	100.12	100.49	100.86	101.23	101.60	101.98	102.35
0.67	102.73	103.11	103.49	103.87	104.25	104.63	105.02	105.40	105.79	106.18
0.68	106.57	106.96	107.35	107.74	108.13	108.53	108.93	109.32	109.72	110.12
0.69	110.52	110.93	111.33	111.74	112.14	112.55	112.96	113.37	113.79	114.20
0.70	114.61	115.03	115.45	115.87	116.29	116.71	117.14	117.56	117.99	118.42
0.71	118.85	119.29	119.72	120.16	120.60	121.04	121.48	121.93	122.37	122.82
0.72	123.28	123.73	124.18	124.64	125.10	125.57	126.03	126.50	126.97	127.44
0.73	127.91	128.39	128.87	129.35	129.84	130.32	130.81	131.31	131.80	132.30
0.74	132.80	133.30	133.81	134.31	134.82	135.34	135.85	136.37	136.90	137.42

Values of F_x — Pipe Taps

β	0	1	2	3	4	5	6	7	8	9
0.10	2.033	2.074	2.115	2.157	2.199	2.241	2.284	2.328	2.372	2.416
0.11	2.451	2.506	2.551	2.597	2.643	2.690	2.737	2.785	2.833	2.881
0.12	2.930	2.979	3.029	3.079	3.130	3.181	3.232	3.284	3.336	3.389
0.13	3.442	3.495	3.549	3.604	3.659	3.714	3.769	3.826	3.882	3.939
0.14	3.995	4.054	4.113	4.171	4.231	4.290	4.350	4.410	4.471	4.533
0.15	4.595	4.657	4.719	4.782	4.846	4.910	4.974	5.039	5.105	5.170
0.16	5.237	5.303	5.370	5.438	5.506	5.574	5.643	5.713	5.782	5.853
0.17	5.923	5.995	6.066	6.138	6.211	6.284	6.357	6.431	6.506	6.580
0.18	6.655	6.731	6.808	6.884	6.962	7.039	7.117	7.196	7.275	7.354
0.19	7.434	7.515	7.596	7.677	7.759	7.841	7.924	8.007	8.091	8.175
0.20	8.260	8.345	8.431	8.517	8.604	8.691	8.778	8.866	8.955	9.044
0.21	9.134	9.224	9.314	9.405	9.497	9.589	9.681	9.774	9.868	9.962
0.22	10.056	10.151	10.247	10.343	10.439	10.536	10.634	10.732	10.830	10.929
0.23	11.029	11.129	11.230	11.331	11.432	11.534	11.637	11.740	11.844	11.948
0.24	12.052	12.158	12.263	12.370	12.476	12.584	12.691	12.800	12.909	13.018
0.25	13.128	13.238	13.349	13.461	13.573	13.685	13.798	13.912	14.026	14.140
0.26	14.256	14.371	14.488	14.604	14.722	14.840	14.958	15.077	15.196	15.317
0.27	15.437	15.558	15.680	15.802	15.925	16.048	16.172	16.297	16.422	16.547
0.28	16.673	16.800	16.927	17.055	17.184	17.313	17.442	17.572	17.703	17.834
0.29	17.966	18.098	18.231	18.365	18.499	18.634	18.769	18.905	19.041	19.178
0.30	19.316	19.454	19.593	19.732	19.872	20.013	20.154	20.296	20.438	20.581
0.31	20.725	20.869	21.014	21.159	21.305	21.452	21.599	21.747	21.896	22.045
0.32	22.195	22.345	22.496	22.648	22.800	22.953	23.106	23.260	23.415	23.571
0.33	23.727	23.884	24.041	24.199	24.357	24.517	24.677	24.837	24.998	25.160
0.34	25.323	25.486	25.650	25.815	25.980	26.146	26.312	26.480	26.648	26.816
0.35	25.986	27.156	27.326	27.498	27.670	27.842	28.016	28.190	28.365	28.540
0.36	28.717	28.894	29.071	29.250	29.429	29.609	29.789	29.970	30.152	30.335
0.37	30.518	30.702	30.887	31.073	31.259	31.446	31.634	31.823	32.012	32.202
0.38	32.393	32.585	32.777	32.971	33.164	33.359	33.554	33.750	33.947	34.145
0.39	34.343	34.543	34.743	34.944	35.145	35.348	35.551	35.755	35.960	36.166
0.40	36.372	36.580	36.788	36.997	37.207	37.417	37.629	37.841	38.054	38.268
0.41	38.483	38.699	38.915	39.132	39.351	39.570	39.790	40.010	40.232	40.455
0.42	40.678	40.903	41.128	41.354	41.581	41.809	42.037	42.267	42.497	42.729
0.43	42.961	43.195	43.429	43.664	43.900	44.138	44.376	44.614	44.854	45.095
0.44	45.337	45.580	45.823	46.068	46.314	46.560	46.808	47.057	47.306	47.557
0.45	47.808	48.061	48.314	48.569	48.824	49.081	49.339	49.597	49.857	50.118
0.46	50.380	50.643	50.907	51.171	51.437	51.704	51.972	52.242	52.512	52.783
0.47	53.056	53.329	53.604	53.880	54.156	54.434	54.713	54.994	55.275	55.557
0.48	55.841	56.126	56.411	56.699	56.987	57.276	57.567	57.859	58.153	58.446
0.49	58.741	59.038	59.335	59.634	59.934	60.236	60.538	60.842	61.147	61.454
0.50	61.761	62.070	62.381	62.692	63.005	63.319	63.634	63.951	64.269	64.588
0.51	64.908	65.230	65.553	65.878	66.204	66.531	66.859	67.189	67.521	67.853
0.52	68.187	68.523	68.860	69.198	69.538	69.879	70.221	70.566	70.911	71.258
0.53	71.606	71.956	72.307	72.660	73.015	73.371	73.728	74.087	74.447	74.809
0.54	75.172	75.537	75.904	76.272	76.642	77.013	77.385	77.760	78.135	78.513
0.55	78.890	79.272	79.655	80.039	80.426	80.814	81.202	81.593	81.986	82.380
0.56	82.776	83.174	83.573	83.974	84.377	84.782	85.188	85.597	86.007	86.419
0.57	86.832	87.248	87.668	88.084	88.505	88.928	89.353	89.780	90.208	90.639
0.58	91.071	91.505	91.942	92.380	92.820	93.262	93.706	94.152	94.600	95.051
0.59	95.503	95.957	96.413	96.872	97.332	97.794	98.258	98.725	99.194	99.665
0.60	100.14	100.61	101.09	101.57	102.05	102.54	103.02	103.51	104.00	104.50
0.61	104.99	105.49	105.99	106.49	107.00	107.50	108.01	108.52	109.04	109.55
0.62	110.07	110.60	111.12	111.65	112.18	112.71	113.24	113.78	114.32	114.86
0.63	115.40	115.95	116.50	117.05	117.61	118.16	118.72	119.29	119.85	120.42
0.64	120.99	121.57	122.14	122.72	123.30	123.89	124.48	125.07	125.66	126.26
0.65	126.86	127.46	128.07	128.68	129.29	129.90	130.52	131.14	131.77	132.39
0.66	133.03	133.66	134.30	134.94	135.58	136.23	136.88	137.53	138.19	138.85
0.67	139.51	140.18	140.85	141.52	142.20	142.88	143.56	144.25	144.94	145.64
0.68	146.34	147.04	147.75	148.46	149.17	149.89	150.61	151.33	152.06	152.80
0.69	153.53	154.27	155.02	155.77	156.52	157.28	158.04	158.81	159.57	160.35
0.70	161.13	161.91	162.70	163.49	164.28	165.08	165.89	166.69	167.51	168.33
0.71	169.15	169.98	170.81	171.64	172.49	173.33	174.18	175.04	175.90	176.76
0.72	177.63	178.51	179.39	180.28	181.17	182.06	182.97	183.87	184.78	185.70
0.73	186.63	187.55	188.49	189.43	190.37	191.32	192.28	193.25	194.21	195.18
0.74	196.17	197.15	198.14	199.14	200.15	201.16	202.17	203.20	204.23	205.26

TABLE 4

Values of F_1 — Flange Taps

β	0	1	2	3	4	5	6	7	8	9
0.10	201.38	201.36	201.33	201.30	201.28	201.25	201.23	201.20	201.18	201.16
0.11	201.13	201.12	201.10	201.08	201.06	201.04	201.02	201.00	200.99	200.97
0.12	200.96	200.94	200.93	200.92	200.91	200.89	200.88	200.87	200.86	200.85
0.13	200.83	200.82	200.82	200.81	200.80	200.79	200.79	200.78	200.77	200.77
0.14	200.77	200.76	200.76	200.76	200.76	200.75	200.75	200.75	200.75	200.75
0.15	200.75	200.75	200.75	200.75	200.76	200.76	200.76	200.76	200.77	200.77
0.16	200.78	200.78	200.79	200.79	200.80	200.81	200.81	200.82	200.83	200.84
0.17	200.85	200.86	200.87	200.87	200.88	200.89	200.91	200.92	200.93	200.94
0.18	200.95	200.97	200.98	200.99	201.00	201.02	201.03	201.04	201.06	201.07
0.19	201.09	201.10	201.11	201.13	201.14	201.16	201.17	201.19	201.20	201.22
0.20	201.23	201.25	201.26	201.28	201.29	201.31	201.32	201.34	201.35	201.37
0.21	201.38	201.40	201.41	201.43	201.44	201.46	201.47	201.49	201.50	201.52
0.22	201.53	201.55	201.56	201.58	201.60	201.61	201.63	201.64	201.66	201.67
0.23	201.69	201.71	201.72	201.74	201.75	201.77	201.78	201.80	201.82	201.83
0.24	201.85	201.87	201.88	201.90	201.91	201.93	201.95	201.96	201.98	202.00
0.25	202.01	202.03	202.05	202.06	202.08	202.10	202.11	202.13	202.15	202.17
0.26	202.18	202.20	202.22	202.24	202.26	202.27	202.29	202.31	202.33	202.34
0.27	202.36	202.38	202.40	202.42	202.43	202.45	202.47	202.49	202.51	202.53
0.28	202.55	202.56	202.58	202.60	202.62	202.64	202.66	202.68	202.70	202.72
0.29	202.74	202.76	202.78	202.80	202.82	202.84	202.86	202.88	202.90	202.92
0.30	202.94	202.96	202.98	203.00	203.03	203.05	203.07	203.09	203.11	203.13
0.31	203.15	203.18	203.20	203.22	203.24	203.26	203.29	203.31	203.33	203.36
0.32	203.38	203.40	203.43	203.45	203.47	203.50	203.52	203.54	203.57	203.59
0.33	203.62	203.64	203.67	203.69	203.72	203.74	203.77	203.79	203.82	203.84
0.34	203.87	203.89	203.92	203.95	203.97	204.00	204.03	204.05	204.08	204.11
0.35	204.13	204.16	204.19	204.22	204.24	204.27	204.30	204.33	204.36	204.39
0.36	204.42	204.44	204.47	204.50	204.53	204.56	204.59	204.62	204.65	204.68
0.37	204.71	204.75	204.78	204.81	204.84	204.87	204.90	204.94	204.97	205.00
0.38	205.03	205.06	205.10	205.13	205.17	205.20	205.23	205.27	205.30	205.33
0.39	205.37	205.40	205.44	205.47	205.51	205.54	205.58	205.62	205.65	205.69
0.40	205.73	205.76	205.80	205.84	205.88	205.91	205.95	205.99	206.03	206.07
0.41	206.11	206.15	206.19	206.23	206.27	206.31	206.35	206.39	206.43	206.47
0.42	206.51	206.55	206.59	206.64	206.68	206.72	206.76	206.81	206.85	206.89
0.43	206.94	206.98	207.03	207.07	207.12	207.16	207.21	207.25	207.30	207.35
0.44	207.39	207.44	207.49	207.54	207.58	207.63	207.68	207.73	207.78	207.83
0.45	207.87	207.92	207.98	208.02	208.07	208.13	208.18	208.23	208.28	208.33
0.46	208.39	208.44	208.49	208.54	208.60	208.65	208.71	208.76	208.82	208.87
0.47	208.93	208.98	209.04	209.09	209.15	209.21	209.27	209.32	209.38	209.44
0.48	209.50	209.56	209.62	209.68	209.74	209.80	209.86	209.92	209.98	210.04
0.49	210.10	210.16	210.23	210.29	210.35	210.42	210.48	210.55	210.61	210.67
0.50	210.74	210.80	210.87	210.94	211.00	211.07	211.14	211.20	211.27	211.34
0.51	211.41	211.48	211.55	211.62	211.69	211.76	211.83	211.90	211.97	212.04
0.52	212.12	212.19	212.27	212.34	212.41	212.49	212.56	212.64	212.72	212.79
0.53	212.87	212.95	213.03	213.10	213.18	213.26	213.34	213.42	213.50	213.58
0.54	213.66	213.75	213.83	213.91	214.00	214.08	214.16	214.25	214.33	214.42
0.55	214.51	214.59	214.68	214.77	214.86	214.94	215.03	215.12	215.21	215.30
0.56	215.39	215.49	215.58	215.67	215.76	215.86	215.95	216.05	216.14	216.24
0.57	216.33	216.43	216.53	216.62	216.72	216.82	216.92	217.02	217.12	217.22
0.58	217.32	217.42	217.52	217.63	217.73	217.84	217.94	218.05	218.15	218.26
0.59	218.36	218.47	218.58	218.69	218.80	218.91	219.02	219.13	219.24	219.35
0.60	219.46	219.57	219.69	219.80	219.92	220.03	220.15	220.26	220.38	220.50
0.61	220.61	220.73	220.85	220.97	221.09	221.21	221.34	221.46	221.58	221.70
0.62	221.83	221.95	222.08	222.20	222.33	222.46	222.59	222.71	222.84	222.97
0.63	223.10	223.24	223.37	223.50	223.63	223.76	223.90	224.03	224.17	224.30
0.64	224.44	224.58	224.72	224.85	224.99	225.13	225.27	225.42	225.56	225.70
0.65	225.84	225.99	226.13	226.28	226.42	226.57	226.72	226.86	227.01	227.16
0.66	227.31	227.46	227.61	227.77	227.92	228.07	228.23	228.38	228.54	228.69
0.67	228.85	229.01	229.17	229.33	229.49	229.65	229.81	229.97	230.13	230.30
0.68	230.46	230.63	230.79	230.96	231.13	231.30	231.46	231.63	231.80	231.98
0.69	232.15	232.32	232.49	232.67	232.84	233.02	233.19	233.37	233.55	233.73
0.70	233.91	234.09	234.27	234.45	234.64	234.83	235.01	235.20	235.39	235.58
0.71	235.77	235.96	236.16	235.35	235.56	236.76	235.97	237.17	237.38	237.59
0.72	237.80	238.01	238.23	238.45	238.67	238.89	239.11	239.34	239.57	239.80
0.73	240.03	240.27	240.51	240.75	240.99	241.24	241.49	241.74	241.99	242.25
0.74	242.51	242.77	243.03	243.30	243.57	243.84	244.12	244.39	244.67	244.96

Values of F_1 — Pipe Taps

β	0	1	2	3	4	5	6	7	8	9
0.10	203.28	203.28	203.29	203.29	203.30	203.30	203.31	203.32	203.33	203.34
0.11	203.35	203.36	203.37	203.38	203.39	203.40	203.41	203.43	203.44	203.46
0.12	203.47	203.49	203.51	203.52	203.54	203.56	203.58	203.60	203.62	203.64
0.13	203.66	203.68	203.70	203.73	203.75	203.77	203.80	203.82	203.85	203.87
0.14	203.90	203.93	203.96	203.98	204.01	204.04	204.07	204.10	204.13	204.17
0.15	204.20	204.23	204.27	204.30	204.33	204.37	204.40	204.44	204.48	204.52
0.16	204.55	204.59	204.63	204.67	204.71	204.75	204.79	204.83	204.87	204.92
0.17	204.96	205.00	205.05	205.09	205.14	205.18	205.23	205.28	205.32	205.37
0.18	205.42	205.47	205.52	205.57	205.62	205.67	205.72	205.77	205.83	205.88
0.19	205.93	205.99	206.04	206.10	206.15	206.21	206.27	206.32	206.38	206.44
0.20	206.50	206.56	206.62	206.68	206.74	206.80	206.86	206.92	206.98	207.05
0.21	207.11	207.18	207.24	207.31	207.37	207.44	207.50	207.57	207.64	207.71
0.22	207.78	207.84	207.91	207.98	208.05	208.13	208.20	208.27	208.34	208.41
0.23	208.49	208.56	208.63	208.71	208.78	208.86	208.93	209.01	209.09	209.17
0.24	209.24	209.32	209.40	209.48	209.56	209.64	209.72	209.80	209.88	209.96
0.25	210.04	210.13	210.21	210.29	210.37	210.46	210.54	210.63	210.71	210.80
0.26	210.88	210.97	211.05	211.14	211.23	211.31	211.40	211.49	211.58	211.67
0.27	211.76	211.85	211.94	212.03	212.12	212.21	212.30	212.39	212.48	212.58
0.28	212.67	212.76	212.86	212.95	213.05	213.14	213.24	213.33	213.43	213.53
0.29	213.62	213.72	213.82	213.92	214.02	214.12	214.22	214.32	214.42	214.52
0.30	214.62	214.72	214.82	214.93	215.03	215.13	215.24	215.34	215.45	215.55
0.31	215.66	214.77	215.87	215.98	216.09	216.20	216.30	216.41	216.52	216.63
0.32	216.74	216.85	216.97	217.08	217.19	217.30	217.42	217.53	217.65	217.76
0.33	217.88	217.99	218.11	218.23	218.34	218.46	218.58	218.70	218.82	218.94
0.34	219.06	219.18	219.30	219.42	219.54	219.67	219.79	219.91	220.04	220.16
0.35	220.29	220.42	220.54	220.67	220.80	220.93	221.06	221.19	221.32	221.45
0.36	221.58	221.71	221.84	221.98	222.11	222.24	222.38	222.51	222.65	222.79
0.37	222.92	223.06	223.20	223.34	223.48	223.62	223.76	223.90	224.04	224.18
0.38	224.33	224.47	224.62	224.77	224.91	225.05	225.20	225.35	225.49	225.64
0.39	225.79	225.94	226.10	226.25	226.40	226.55	226.71	226.86	227.02	227.17
0.40	227.33	227.48	227.64	227.80	227.96	228.12	228.28	228.44	228.60	228.76
0.41	228.93	229.09	229.25	229.42	229.59	229.76	229.92	230.09	230.26	230.43
0.42	230.60	230.77	230.95	231.12	231.29	231.47	231.64	231.82	231.99	232.17
0.43	232.35	232.53	232.71	232.89	233.07	233.25	233.44	233.62	233.81	233.99
0.44	234.18	234.37	234.55	234.74	234.93	235.12	235.31	235.51	235.70	235.90
0.45	236.09	236.29	236.48	236.68	236.88	237.08	237.28	237.48	237.68	237.88
0.46	238.09	238.29	238.50	238.71	238.91	239.12	239.33	239.54	239.75	239.97
0.47	240.18	240.39	240.61	240.83	241.04	241.26	241.48	241.70	241.92	242.14
0.48	242.36	242.59	242.81	243.04	243.27	243.50	243.72	243.96	244.19	244.42
0.49	244.65	244.89	245.12	245.36	245.60	245.84	246.07	246.32	246.56	246.80
0.50	247.05	247.29	247.54	247.79	248.03	248.29	248.54	248.79	249.04	249.30
0.51	249.55	249.81	250.07	250.33	250.59	250.85	251.11	251.37	251.64	251.90
0.52	252.17	252.44	252.71	252.98	253.26	253.53	253.80	254.08	254.36	254.64
0.53	254.92	255.20	255.48	255.77	256.05	256.34	256.63	256.92	257.21	257.50
0.54	257.79	258.09	258.38	258.68	258.98	259.28	259.58	259.88	260.19	260.49
0.55	260.79	261.11	261.42	261.73	262.04	262.36	262.68	262.99	263.31	263.63
0.56	263.95	264.28	264.60	264.93	265.26	265.59	265.92	266.25	266.58	266.92
0.57	267.26	267.60	267.95	268.28	268.63	268.97	269.32	269.67	270.02	270.37
0.58	270.72	271.08	271.44	271.79	272.16	272.52	272.88	273.25	273.61	273.98
0.59	274.35	274.73	275.10	275.48	275.86	276.23	276.62	277.00	277.39	277.77
0.60	278.16	278.55	278.95	279.35	279.74	280.14	280.54	280.94	281.34	281.75
0.61	282.16	282.57	282.98	283.40	283.81	284.23	284.65	285.07	285.50	285.92
0.62	286.35	286.78	287.22	287.65	288.09	288.53	288.97	289.41	289.86	290.31
0.63	290.76	291.21	291.67	292.12	292.58	293.05	293.51	293.98	294.45	294.92
0.64	295.39	295.87	296.34	296.82	297.31	297.79	298.28	298.77	299.27	299.76
0.65	300.26	300.76	301.27	301.77	302.28	302.79	303.30	303.82	304.34	304.86
0.66	305.39	305.91	306.44	206.98	307.51	308.05	308.59	309.14	309.68	310.23
0.67	310.78	311.34	311.90	312.46	313.02	313.59	314.16	314.74	315.31	315.89
0.68	316.48	317.06	317.65	318.24	318.84	319.44	320.04	320.65	321.25	321.87
0.69	322.48	323.10	323.73	324.35	324.98	325.61	326.25	326.89	327.53	328.18
0.70	328.83	329.49	330.14	330.81	331.47	332.14	332.81	333.49	334.17	334.86
0.71	335.54	336.24	336.94	337.64	338.34	339.05	339.76	340.48	341.20	341.93
0.72	342.66	343.39	344.13	344.88	345.62	346.38	347.13	347.89	348.66	349.43
0.73	350.21	350.99	351.77	352.56	353.36	354.15	354.96	355.78	356.58	357.40
0.74	358.23	359.06	359.89	360.73	361.58	362.43	363.28	364.15	365.01	365.88

TABLE 5

Reynolds Number Factor, F_r "b" Values for Flange Taps

$$F_r = 1 + \frac{b}{\sqrt{h_w p_f}}$$

Orifice Diam., d, Inches	Internal Diameter of Pipe, D, Inches								
	2			3				4	
	1.689	1.939	2.067	2.300	2.626	2.900	3.068	3.152	3.438
.250	.0879	.0911	.0926	.0950					
.375	.0677	.0709	.0726	.0755	.0792	.0820	.0836	.0844	.0867
.500	.0562	.0576	.0588	.0612	.0648	.0677	.0695	.0703	.0728
.625	.0520	.0505	.0506	.0516	.0541	.0566	.0583	.0591	.0618
.750	.0536	.0485	.0471	.0462	.0470	.0486	.0498	.0504	.0528
.875	.0595	.0505	.0478	.0445	.0429	.0433	.0438	.0442	.0460
1.000	.0677	.0559	.0515	.0458	.0416	.0403	.0402	.0403	.0411
1.125	.0762	.0630	.0574	.0495	.0427	.0396	.0386	.0383	.0380
1.250	.0824	.0707	.0646	.0550	.0456	.0408	.0388	.0381	.0365
1.375		.0772	.0715	.0614	.0501	.0435	.0406	.0394	.0365
1.500			.0773	.0679	.0554	.0474	.0436	.0420	.0378
1.625				.0735	.0613	.0522	.0477	.0457	.0402
1.750					.0669	.0575	.0524	.0500	.0434
1.875					.0717	.0628	.0574	.0549	.0473
2.000						.0676	.0624	.0598	.0517
2.125						.0715	.0669	.0642	.0563
2.250							.0706	.0685	.0607
2.375									.0648
2.500									.0683

Orifice Diam., d, Inches	Internal Diameter of Pipe, D, Inches								
	4			6			8		
	3.826	4.026	4.897	5.189	5.761	6.065	7.625	7.981	8.071
.500	.0763	.0779	.0836						
.625	.0653	.0670	.0734	.0753	.0785	.0801			
.750	.0561	.0578	.0645	.0665	.0701	.0718			
.875	.0487	.0502	.0567	.0587	.0625	.0643	.0723	.0738	.0742
1.000	.0430	.0442	.0500	.0520	.0557	.0576	.0660	.0676	.0680
1.125	.0388	.0396	.0444	.0462	.0498	.0517	.0602	.0619	.0623
1.250	.0361	.0364	.0399	.0414	.0447	.0464	.0549	.0566	.0571
1.375	.0347	.0344	.0363	.0375	.0403	.0419	.0501	.0518	.0523
1.500	.0345	.0336	.0336	.0344	.0367	.0381	.0457	.0474	.0479
1.625	.0354	.0338	.0318	.0322	.0337	.0348	.0418	.0435	.0439
1.750	.0372	.0350	.0307	.0306	.0314	.0322	.0383	.0399	.0403
1.875	.0398	.0370	.0305	.0298	.0298	.0303	.0353	.0366	.0371
2.000	.0430	.0395	.0308	.0296	.0287	.0288	.0327	.0340	.0343
2.125	.0467	.0427	.0318	.0300	.0281	.0278	.0304	.0315	.0318
2.250	.0507	.0462	.0334	.0310	.0281	.0274	.0286	.0295	.0297
2.375	.0548	.0501	.0354	.0324	.0286	.0274	.0271	.0278	.0280
2.500	.0589	.0540	.0378	.0342	.0295	.0279	.0259	.0264	.0265
2.625	.0626	.0579	.0406	.0365	.0308	.0287	.0251	.0253	.0254
2.750	.0659	.0615	.0436	.0391	.0324	.0300	.0246	.0245	.0245
2.875		.0647	.0468	.0418	.0343	.0314	.0244	.0240	.0240
3.000			.0500	.0448	.0366	.0332	.0245	.0238	.0237
3.125			.0533	.0479	.0389	.0353	.0248	.0239	.0237
3.250			.0564	.0510	.0416	.0375	.0254	.0242	.0240
3.375			.0594	.0541	.0443	.0400	.0263	.0248	.0244
3.500			.0620	.0569	.0472	.0426	.0273	.0255	.0251
3.625			.0643	.0597	.0500	.0452	.0286	.0265	.0260
3.750				.0621	.0527	.0479	.0300	.0274	.0271
3.875				.0640	.0553	.0505	.0316	.0289	.0283
4.000					.0578	.0531	.0334	.0304	.0297
4.250					.0620	.0579	.0372	.0338	.0330
4.500						.0618	.0414	.0386	.0366
4.750							.0457	.0416	.0405
5.000							.0500	.0457	.0446
5.250							.0539	.0497	.0487
5.500							.0574	.0535	.0524
5.750								.0569	.0559
6.000									.0588

Orifice Diam., d, Inches	Internal Diameter of Pipe, D, Inches								
	10			12			16		
	9.564	10.020	10.136	11.376	11.938	12.090	14.688	15.000	15.250
1.000	.0738								
1.125	.0685	.0701	.0705						
1.250	.0635	.0652	.0656	.0698	.0714	.0718			
1.375	.0588	.0606	.0610	.0654	.0671	.0676			
1.500	.0545	.0563	.0568	.0612	.0631	.0635	.0706	.0713	
1.625	.0504	.0523	.0527	.0573	.0592	.0597	.0670	.0678	.0684
1.750	.0467	.0485	.0490	.0536	.0555	.0560	.0636	.0644	.0650
1.875	.0433	.0451	.0455	.0501	.0521	.0526	.0604	.0612	.0618
2.000	.0401	.0419	.0414	.0469	.0488	.0492	.0572	.0581	.0587
2.125	.0372	.0389	.0383	.0438	.0458	.0463	.0542	.0551	.0558
2.250	.0346	.0362	.0356	.0410	.0429	.0434	.0514	.0523	.0529
2.375	.0322	.0337	.0330	.0383	.0402	.0407	.0487	.0496	.0502
2.500	.0302	.0315	.0308	.0359	.0377	.0382	.0461	.0470	.0476
2.625	.0283	.0296	.0287	.0336	.0354	.0358	.0436	.0445	.0452
2.750	.0267	.0278	.0269	.0316	.0332	.0336	.0413	.0422	.0428
2.875	.0254	.0263	.0253	.0297	.0312	.0317	.0391	.0399	.0406
3.000	.0243	.0250	.0252	.0278	.0294	.0298	.0370	.0378	.0385
3.125	.0234	.0239	.0241	.0264	.0278	.0282	.0350	.0358	.0365
3.250	.0225	.0230	.0231	.0251	.0263	.0266	.0331	.0339	.0346
3.375	.0221	.0223	.0224	.0239	.0250	.0253	.0314	.0321	.0328
3.500	.0219	.0218	.0218	.0229	.0238	.0241	.0298	.0305	.0311
3.625	.0218	.0214	.0214	.0221	.0228	.0230	.0282	.0290	.0295
3.750	.0218	.0213	.0212	.0214	.0219	.0221	.0268	.0275	.0281
3.875	.0221	.0213	.0211	.0208	.0212	.0213	.0255	.0262	.0267
4.000	.0225	.0214	.0212	.0204	.0206	.0207	.0243	.0249	.0254
4.250	.0238	.0222	.0219	.0200	.0198	.0198	.0223	.0228	.0232
4.500	.0256	.0236	.0231	.0201	.0195	.0194	.0206	.0210	.0213
4.750	.0279	.0254	.0249	.0207	.0196	.0194	.0193	.0196	.0198
5.000	.0307	.0277	.0270	.0217	.0202	.0199	.0184	.0185	.0187
5.250	.0337	.0303	.0295	.0231	.0212	.0208	.0178	.0178	.0179
5.500	.0370	.0332	.0323	.0249	.0226	.0221	.0176	.0174	.0174
5.750	.0404	.0363	.0354	.0270	.0243	.0237	.0176	.0174	.0172
6.000	.0438	.0396	.0386	.0294	.0263	.0255	.0180	.0176	.0173
6.250	.0473	.0437	.0418	.0320	.0285	.0277	.0186	.0180	.0177
6.500	.0505	.0462	.0451	.0347	.0309	.0300	.0195	.0188	.0183
6.750	.0536	.0493	.0483	.0376	.0335	.0325	.0206	.0198	.0192
7.000	.0562	.0523	.0513	.0406	.0362	.0351	.0220	.0210	.0202
7.250		.0550	.0540	.0435	.0390	.0379	.0235	.0224	.0216
7.500		.0572	.0564	.0463	.0418	.0407	.0252	.0240	.0230
7.750				.0491	.0446	.0434	.0271	.0257	.0246
8.000				.0517	.0473	.0461	.0291	.0276	.0264
8.250				.0540	.0498	.0487	.0312	.0296	.0283
8.500				.0560	.0522	.0511	.0334	.0317	.0303
8.750					.0543	.0534	.0357	.0338	.0324
9.000						.0553	.0380	.0361	.0346
9.250							.0402	.0383	.0368
9.500							.0425	.0406	.0390
9.750							.0447	.0428	.0412
10.000							.0469	.0449	.0434
10.250							.0489	.0470	.0455
10.500							.0508	.0490	.0475
10.750							.0526	.0509	.0495
11.000							.0541	.0526	.0513
11.250								.0541	.0528

Orifice Diam., d, Inches	Internal Diameter of Pipe, D, Inches								
	20			24			30		
	18.814	19.000	19.250	22.626	23.000	23.250	28.628	29.000	29.250
2.000	.0667	.0671	.0676						
2.125	.0640	.0644	.0649						
2.250	.0614	.0618	.0622						
2.375	.0588	.0592	.0597	.0659	.0665	.0669			
2.500	.0563	.0568	.0573	.0636	.0642	.0646			
2.625	.0540	.0544	.0549	.0614	.0620	.0624			
2.750	.0517	.0521	.0526	.0592	.0599	.0603			
2.875	.0494	.0499	.0504	.0571	.0578	.0582	.0662		
3.000	.0473	.0477	.0483	.0551	.0557	.0562	.0644	.0649	.0652
3.125	.0452	.0457	.0462	.0531	.0538	.0542	.0626	.0631	.0634
3.250	.0433	.0437	.0442	.0511	.0520	.0523	.0608	.0613	.0616
3.375	.0414	.0418	.0423	.0493	.0500	.0504	.0590	.0596	.0599
3.500	.0395	.0399	.0405	.0474	.0481	.0486	.0574	.0579	.0582
3.625	.0378	.0382	.0387	.0457	.0464	.0468	.0557	.0562	.0566
3.750	.0361	.0365	.0370	.0440	.0447	.0451	.0541	.0546	.0550
3.875	.0345	.0349	.0354	.0423	.0430	.0435	.0525	.0530	.0534
4.000	.0329	.0333	.0339	.0407	.0414	.0419	.0509	.0515	.0518
4.250	.0301	.0304	.0310	.0376	.0384	.0388	.0479	.0485	.0488
4.500	.0275	.0279	.0283	.0348	.0355	.0360	.0450	.0456	.0460
4.750	.0252	.0256	.0260	.0322	.0328	.0333	.0423	.0429	.0433
5.000	.0232	.0235	.0239	.0297	.0304	.0308	.0397	.0403	.0407
5.250	.0214	.0217	.0220	.0275	.0281	.0285	.0373	.0378	.0382
5.500	.0199	.0201	.0204	.0254	.0260	.0264	.0349	.0355	.0359
5.750	.0186	.0188	.0191	.0236	.0241	.0245	.0327	.0333	.0337
6.000	.0176	.0177	.0179	.0219	.0224	.0228	.0306	.0312	.0316
6.250	.0167	.0168	.0170	.0204	.0208	.0212	.0287	.0292	.0296
6.500	.0161	.0162	.0163	.0191	.0195	.0198	.0269	.0274	.0277
6.750	.0157	.0157	.0157	.0179	.0183	.0185	.0252	.0257	.0260
7.000	.0155	.0155	.0154	.0169	.0172	.0174	.0236	.0240	.0244
7.250	.0155	.0154	.0153	.0161	.0163	.0165	.0221	.0226	.0229
7.500	.0157	.0155	.0154	.0154	.0156	.0157	.0208	.0212	.0215
7.750	.0160	.0158	.0156	.0148	.0150	.0151	.0195	.0199	.0202
8.000	.0166	.0163	.0160	.0144	.0145	.0146	.0184	.0187	.0190
8.250	.0172	.0169	.0165	.0142	.0142	.0142	.0174	.0177	.0179
8.500	.0180	.0177	.0172	.0141	.0140	.0140	.0164	.0168	.0170
8.750	.0190	.0186	.0180	.0141	.0140	.0139	.0156	.0159	.0161
9.000	.0201	.0196	.0190	.0143	.0141	.0140	.0149	.0152	.0153
9.250	.0213	.0208	.0201	.0146	.0143	.0141	.0143	.0145	.0146
9.500	.0226	.0220	.0213	.0150	.0146	.0144	.0138	.0139	.0141
9.750	.0240	.0234	.0226	.0155	.0150	.0147	.0133	.0135	.0136
10.000	.0256	.0249	.0240	.0161	.0155	.0152	.0130	.0131	.0132
10.250	.0271	.0264	.0255	.0168	.0162	.0158	.0128	.0128	.0128
10.500	.0288	.0280	.0270	.0176	.0169	.0164	.0126	.0126	.0126
10.750	.0305	.0297	.0286	.0185	.0176	.0172	.0125	.0125	.0125
11.000	.0322	.0314	.0303	.0194	.0186	.0181	.0125	.0124	.0124
11.250	.0340	.0332	.0320	.0205	.0196	.0190	.0126	.0125	.0124
11.500	.0358	.0349	.0338	.0216	.0207	.0200	.0128	.0126	.0125
11.750	.0376	.0367	.0355	.0228	.0218	.0211	.0130	.0128	.0127
12.000	.0394	.0385	.0373	.0241	.0230	.0223	.0134	.0131	.0129
12.500	.0429	.0420	.0408	.0267	.0255	.0248	.0142	.0138	.0136
13.000	.0463	.0454	.0442	.0296	.0282	.0274	.0153	.0148	.0145
13.500	.0494	.0485	.0474	.0326	.0311	.0302	.0166	.0160	.0157
14.000	.0520	.0512	.0502	.0356	.0341	.0331	.0182	.0175	.0171
14.500				.0386	.0370	.0360	.0199	.0192	.0187
15.000				.0415	.0400	.0390	.0218	.0209	.0204
15.500				.0443	.0428	.0418	.0239	.0230	.0224
16.000				.0470	.0455	.0446	.0260	.0250	.0244
16.500				.0494	.0480	.0471	.0283	.0273	.0266
17.000					.0503	.0494	.0307	.0296	.0288
17.500							.0331	.0319	.0312
18.000							.0355	.0343	.0335
18.500							.0379	.0366	.0358
19.000							.0402	.0390	.0382
19.500							.0424	.0412	.0404
20.000							.0446	.0434	.0426
20.500							.0466	.0455	.0448
21.000							.0485	.0475	.0467
21.500								.0492	.0485

TABLE 5-A

Reynolds Number Factor, F_r
"b" Values for Flange Taps

$$F_r = 1 + \frac{b}{\sqrt{h_w p_f}}$$

β	Internal diameter of pipe in inches, D: 2			3				4				6
	1.689	1.939	2.067	2.300	2.626	2.900	3.068	3.152	3.438	3.826	4.026	4.897
0.10	1.0111	1.0088	1.0078	1.0063	1.0047	1.0037	1.0027	1.0024	1.0015	1.0005	1.0000	0.9983
0.11	1.0101	1.0080	1.0071	1.0057	1.0041	1.0031	1.0025	1.0022	1.0014	1.0004		0.9985
0.12	1.0092	1.0073	1.0065	1.0052	1.0038	1.0028	1.0022	1.0020	1.0012	1.0004		0.9986
0.13	1.0084	1.0067	1.0059	1.0047	1.0034	1.0025	1.0020	1.0018	1.0011	1.0003		0.9988
0.14	1.0077	1.0061	1.0054	1.0042	1.0031	1.0023	1.0018	1.0016	1.0010	1.0003		0.9989
0.15	1.0071	1.0056	1.0049	1.0039	1.0028	1.0021	1.0017	1.0015	1.0009	1.0003	1.0000	0.9990
0.16	1.0065	1.0051	1.0045	1.0036	1.0026	1.0019	1.0015	1.0014	1.0008	1.0003		0.9991
0.17	1.0060	1.0047	1.0041	1.0033	1.0024	1.0017	1.0014	1.0012	1.0008	1.0002		0.9992
0.18	1.0055	1.0043	1.0038	1.0030	1.0022	1.0016	1.0013	1.0011	1.0007	1.0002		0.9993
0.19	1.0051	1.0040	1.0035	1.0028	1.0020	1.0015	1.0012	1.0010	1.0006	1.0002		0.9993
0.20	1.0047	1.0037	1.0033	1.0026	1.0018	1.0013	1.0011	1.0010	1.0006	1.0002	1.0000	0.9994
0.21	1.0044	1.0035	1.0030	1.0024	1.0017	1.0013	1.0010	1.0009	1.0006	1.0002		0.9994
0.22	1.0042	1.0033	1.0029	1.0023	1.0016	1.0012	1.0009	1.0008	1.0005	1.0002		0.9995
0.23	1.0040	1.0031	1.0027	1.0021	1.0015	1.0011	1.0009	1.0008	1.0005	1.0001		0.9995
0.24	1.0038	1.0029	1.0026	1.0020	1.0015	1.0011	1.0008	1.0008	1.0005	1.0001		0.9995
0.25	1.0036	1.0028	1.0024	1.0019	1.0014	1.0010	1.0008	1.0007	1.0004	1.0001	1.0000	0.9995
0.26	1.0034	1.0027	1.0023	1.0019	1.0013	1.0010	1.0008	1.0007	1.0004	1.0001		0.9996
0.27	1.0032	1.0025	1.0022	1.0018	1.0012	1.0009	1.0007	1.0006	1.0004	1.0001		0.9996
0.28	1.0031	1.0024	1.0021	1.0017	1.0012	1.0009	1.0007	1.0006	1.0004	1.0001		0.9996
0.29	1.0029	1.0022	1.0020	1.0016	1.0011	1.0008	1.0007	1.0006	1.0004	1.0001		0.9996
0.30	1.0027	1.0021	1.0018	1.0015	1.0010	1.0008	1.0006	1.0005	1.0003	1.0001	1.0000	0.9997
0.31	1.0025	1.0020	1.0017	1.0014	1.0010	1.0007	1.0006	1.0005	1.0003	1.0001		0.9997
0.32	1.0023	1.0018	1.0016	1.0013	1.0009	1.0007	1.0005	1.0005	1.0003	1.0001		0.9997
0.33	1.0022	1.0017	1.0015	1.0012	1.0008	1.0006	1.0005	1.0004	1.0003	1.0001		0.9997
0.34	1.0020	1.0016	1.0014	1.0011	1.0008	1.0006	1.0005	1.0004	1.0002	1.0001		0.9997
0.35	1.0018	1.0014	1.0012	1.0010	1.0007	1.0005	1.0004	1.0004	1.0002	1.0001	1.0000	0.9998
0.36	1.0017	1.0013	1.0011	1.0009	1.0006	1.0005	1.0004	1.0003	1.0002	1.0001		0.9998
0.37	1.0015	1.0012	1.0010	1.0008	1.0006	1.0004	1.0003	1.0003	1.0002	1.0001		0.9998
0.38	1.0013	1.0010	1.0009	1.0007	1.0005	1.0004	1.0003	1.0003	1.0002	1.0001		0.9998
0.39	1.0012	1.0009	1.0008	1.0007	1.0005	1.0003	1.0003	1.0002	1.0001	1.0000		0.9998
0.40	1.0011	1.0008	1.0007	1.0006	1.0004	1.0003	1.0002	1.0002	1.0001	1.0000	1.0000	0.9999
0.41	1.0009	1.0007	1.0006	1.0005	1.0004	1.0003	1.0002	1.0002	1.0001	1.0000		0.9999
0.42	1.0008	1.0006	1.0006	1.0004	1.0003	1.0002	1.0002	1.0002	1.0001	1.0000		0.9999
0.43	1.0007	1.0005	1.0005	1.0004	1.0003	1.0002	1.0002	1.0001	1.0001	1.0000		0.9999
0.44	1.0006	1.0005	1.0004	1.0003	1.0002	1.0002	1.0001	1.0001	1.0001	1.0000		0.9999
0.45	1.0005	1.0004	1.0003	1.0003	1.0002	1.0001	1.0001	1.0001	1.0001	1.0000	1.0000	0.9999
0.46	1.0004	1.0003	1.0003	1.0002	1.0002	1.0001	1.0001	1.0001	1.0001	1.0000		0.9999
0.47	1.0004	1.0003	1.0003	1.0002	1.0001	1.0001	1.0001	1.0001	1.0000	1.0000		1.0000
0.48	1.0003	1.0003	1.0002	1.0002	1.0001	1.0001	1.0001	1.0001	1.0000	1.0000		1.0000
0.49	1.0003	1.0002	1.0002	1.0002	1.0001	1.0001	1.0001	1.0001	1.0000	1.0000		1.0000
0.50	1.0003	1.0002	1.0002	1.0002	1.0001	1.0001	1.0001	1.0001	1.0000	1.0000	1.0000	1.0000
0.51	1.0003	1.0002	1.0002	1.0002	1.0001	1.0001	1.0001	1.0001	1.0000	1.0000		1.0000
0.52	1.0003	1.0003	1.0002	1.0002	1.0001	1.0001	1.0001	1.0001	1.0000	1.0000		1.0000
0.53	1.0004	1.0003	1.0003	1.0002	1.0002	1.0001	1.0001	1.0001	1.0000	1.0000		1.9999
0.54	1.0005	1.0004	1.0003	1.0003	1.0002	1.0001	1.0001	1.0001	1.0001	1.0000		0.9999
0.55	1.0006	1.0004	1.0004	1.0003	1.0002	1.0002	1.0001	1.0001	1.0001	1.0000	1.0000	0.9999
0.56	1.0007	1.0005	1.0005	1.0004	1.0003	1.0002	1.0002	1.0001	1.0001	1.0000		0.9999
0.57	1.0008	1.0006	1.0006	1.0004	1.0003	1.0002	1.0002	1.0002	1.0001	1.0000		0.9999
0.58	1.0010	1.0008	1.0007	1.0005	1.0004	1.0003	1.0002	1.0002	1.0001	1.0000		0.9999
0.59	1.0012	1.0009	1.0008	1.0006	1.0004	1.0003	1.0003	1.0002	1.0001	1.0000		0.9999
0.60	1.0014	1.0011	1.0009	1.0007	1.0005	1.0004	1.0003	1.0003	1.0002	1.0001	1.0000	0.9998
0.61	1.0016	1.0012	1.0011	1.0009	1.0006	1.0005	1.0004	1.0003	1.0002	1.0001		0.9998
0.62	1.0019	1.0015	1.0013	1.0010	1.0007	1.0005	1.0004	1.0004	1.0002	1.0001		0.9998
0.63	1.0022	1.0017	1.0015	1.0012	1.0008	1.0006	1.0005	1.0004	1.0003	1.0001		0.9997
0.64	1.0025	1.0019	1.0017	1.0013	1.0010	1.0007	1.0006	1.0005	1.0003	1.0001		0.9997
0.65	1.0028	1.0022	1.0019	1.0015	1.0011	1.0008	1.0006	1.0006	1.0003	1.0001	1.0000	0.9996
0.66	1.0032	1.0025	1.0022	1.0017	1.0012	1.0009	1.0007	1.0006	1.0004	1.0001		0.9996
0.67	1.0036	1.0028	1.0024	1.0019	1.0014	1.0010	1.0008	1.0007	1.0004	1.0001		0.9995
0.68	1.0040	1.0031	1.0027	1.0022	1.0015	1.0011	1.0009	1.0008	1.0005	1.0001		0.9995
0.69	1.0044	1.0034	1.0030	1.0024	1.0017	1.0012	1.0010	1.0009	1.0005	1.0002		0.9994
0.70	1.0049	1.0038	1.0033	1.0026	1.0019	1.0014	1.0011	1.0010	1.0006	1.0002	1.0000	0.9994
0.71	1.0053	1.0041	1.0036	1.0029	1.0021	1.0015	1.0012	1.0011	1.0007	1.0002		0.9993
0.72	1.0058	1.0045	1.0040	1.0032	1.0022	1.0016	1.0013	1.0012	1.0007	1.0002		0.9993
0.73	1.0063	1.0049	1.0043	1.0034	1.0024	1.0018	1.0014	1.0013	1.0008	1.0002		0.9992
0.74	1.0069	1.0053	1.0047	1.0037	1.0026	1.0019	1.0015	1.0014	1.0008	1.0003		0.9991
0.75	1.0074	1.0058	1.0051	1.0040	1.0029	1.0021	1.0017	1.0015	1.0009	1.0003		0.9990

β	Internal diameter of pipe in inches, D: 6			8			10			12		
	5.189	5.761	6.065	7.625	7.981	8.071	9.564	10.020	10.136	11.376	11.938	12.090
0.10	0.9979	0.9971	0.9968	0.9953	0.9951	0.9950	0.9941	0.9939	0.9938	0.9933	0.9931	0.9930
0.11	0.9981	0.9974	0.9971	0.9958	0.9956	0.9955	0.9947	0.9945	0.9945	0.9940	0.9938	0.9937
0.12	0.9983	0.9977	0.9974	0.9962	0.9960	0.9960	0.9953	0.9951	0.9950	0.9946	0.9944	0.9944
0.13	0.9985	0.9979	0.9976	0.9966	0.9964	0.9964	0.9957	0.9956	0.9955	0.9952	0.9950	0.9950
0.14	0.9986	0.9981	0.9979	0.9970	0.9968	0.9967	0.9962	0.9961	0.9960	0.9957	0.9956	0.9955
0.15	0.9987	0.9983	0.9981	0.9973	0.9971	0.9971	0.9966	0.9965	0.9964	0.9961	0.9960	0.9960
0.16	0.9989	0.9985	0.9983	0.9975	0.9974	0.9974	0.9969	0.9968	0.9968	0.9965	0.9964	0.9964
0.17	0.9990	0.9986	0.9984	0.9978	0.9977	0.9976	0.9972	0.9971	0.9971	0.9969	0.9968	0.9968
0.18	0.9991	0.9987	0.9986	0.9980	0.9979	0.9979	0.9975	0.9974	0.9974	0.9972	0.9971	0.9971
0.19	0.9991	0.9988	0.9987	0.9982	0.9981	0.9981	0.9977	0.9977	0.9976	0.9975	0.9974	0.9974
0.20	0.9992	0.9989	0.9988	0.9983	0.9982	0.9982	0.9979	0.9979	0.9978	0.9977	0.9976	0.9976
0.21	0.9993	0.9990	0.9989	0.9985	0.9984	0.9984	0.9981	0.9980	0.9980	0.9979	0.9978	0.9978
0.22	0.9993	0.9991	0.9990	0.9986	0.9985	0.9985	0.9982	0.9982	0.9982	0.9980	0.9980	0.9980
0.23	0.9994	0.9991	0.9990	0.9986	0.9986	0.9986	0.9983	0.9983	0.9983	0.9981	0.9981	0.9981
0.24	0.9994	0.9992	0.9991	0.9987	0.9987	0.9986	0.9984	0.9984	0.9984	0.9982	0.9982	0.9982
0.25	0.9994	0.9992	0.9991	0.9988	0.9987	0.9987	0.9985	0.9984	0.9984	0.9983	0.9983	0.9983
0.26	0.9994	0.9993	0.9992	0.9988	0.9988	0.9988	0.9986	0.9985	0.9985	0.9984	0.9984	0.9984
0.27	0.9995	0.9993	0.9992	0.9989	0.9988	0.9988	0.9986	0.9986	0.9986	0.9985	0.9984	0.9984
0.28	0.9995	0.9993	0.9993	0.9990	0.9989	0.9989	0.9987	0.9987	0.9987	0.9986	0.9985	0.9985
0.29	0.9995	0.9994	0.9993	0.9990	0.9990	0.9990	0.9988	0.9988	0.9987	0.9987	0.9986	0.9986
0.30	0.9996	0.9994	0.9993	0.9991	0.9990	0.9990	0.9989	0.9988	0.9988	0.9987	0.9987	0.9987
0.31	0.9996	0.9995	0.9994	0.9991	0.9991	0.9991	0.9989	0.9989	0.9989	0.9988	0.9988	0.9988
0.32	0.9996	0.9995	0.9994	0.9992	0.9992	0.9991	0.9990	0.9990	0.9990	0.9989	0.9989	0.9989
0.33	0.9996	0.9995	0.9995	0.9993	0.9992	0.9992	0.9991	0.9991	0.9991	0.9990	0.9990	0.9990
0.34	0.9997	0.9996	0.9995	0.9993	0.9993	0.9993	0.9992	0.9991	0.9991	0.9991	0.9990	0.9990
0.35	0.9997	0.9996	0.9996	0.9994	0.9993	0.9993	0.9992	0.9992	0.9992	0.9991	0.9991	0.9991
0.36	0.9997	0.9996	0.9996	0.9994	0.9994	0.9994	0.9993	0.9993	0.9993	0.9992	0.9992	0.9992
0.37	0.9998	0.9997	0.9996	0.9995	0.9995	0.9995	0.9994	0.9994	0.9993	0.9993	0.9993	0.9993
0.38	0.9998	0.9997	0.9997	0.9995	0.9995	0.9995	0.9994	0.9994	0.9994	0.9994	0.9994	0.9994
0.39	0.9998	0.9997	0.9997	0.9996	0.9996	0.9996	0.9995	0.9995	0.9995	0.9994	0.9994	0.9994
0.40	0.9998	0.9998	0.9997	0.9996	0.9996	0.9996	0.9996	0.9995	0.9995	0.9995	0.9995	0.9995
0.41	0.9998	0.9998	0.9998	0.9997	0.9997	0.9997	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996
0.42	0.9999	0.9998	0.9998	0.9997	0.9997	0.9997	0.9997	0.9997	0.9996	0.9996	0.9996	0.9996
0.43	0.9999	0.9998	0.9998	0.9998	0.9998	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997
0.44	0.9999	0.9999	0.9999	0.9998	0.9998	0.9998	0.9998	0.9997	0.9997	0.9997	0.9997	0.9997
0.45	0.9999	0.9999	0.9999	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998
0.46	0.9999	0.9999	0.9999	0.9999	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998
0.47	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998
0.48	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9998	0.9998	0.9998
0.49	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
0.50	1.0000	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
0.51	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9998
0.52	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9998	0.9998	0.9998
0.53	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998
0.54	0.9999	0.9999	0.9999	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998
0.55	0.9999	0.9999	0.9999	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9997	0.9997	0.9997
0.56	0.9999	0.9999	0.9998	0.9998	0.9998	0.9998	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997
0.57	0.9999	0.9998	0.9998	0.9997	0.9997	0.9997	0.9997	0.9997	0.9996	0.9996	0.9996	0.9996
0.58	0.9998	0.9998	0.9998	0.9997	0.9997	0.9996	0.9996	0.9996	0.9996	0.9995	0.9995	0.9995
0.59	0.9998	0.9997	0.9997	0.9996	0.9996	0.9996	0.9995	0.9995	0.9995	0.9995	0.9994	0.9994
0.60	0.9998	0.9997	0.9997	0.9995	0.9995	0.9995	0.9994	0.9994	0.9994	0.9994	0.9993	0.9993
0.61	0.9997	0.9997	0.9996	0.9995	0.9994	0.9994	0.9993	0.9993	0.9993	0.9993	0.9992	0.9992
0.62	0.9997	0.9996	0.9995	0.9994	0.9993	0.9993	0.9992	0.9992	0.9992	0.9991	0.9991	0.9991
0.63	0.9997	0.9995	0.9995	0.9993	0.9992	0.9992	0.9991	0.9991	0.9991	0.9990	0.9990	0.9990
0.64	0.9996	0.9995	0.9994	0.9992	0.9991	0.9991	0.9990	0.9989	0.9989	0.9988	0.9988	0.9988
0.65	0.9995	0.9994	0.9993	0.9990	0.9990	0.9990	0.9988	0.9988	0.9988	0.9987	0.9987	0.9986
0.66	0.9995	0.9993	0.9992	0.9989	0.9989	0.9989	0.9987	0.9986	0.9986	0.9985	0.9985	0.9985
0.67	0.9994	0.9992	0.9991	0.9988	0.9987	0.9987	0.9985	0.9985	0.9984	0.9983	0.9983	0.9983
0.68	0.9994	0.9991	0.9990	0.9986	0.9986	0.9986	0.9983	0.9983	0.9983	0.9981	0.9981	0.9981
0.69	0.9993	0.9990	0.9989	0.9985	0.9984	0.9984	0.9982	0.9981	0.9981	0.9979	0.9979	0.9979
0.70	0.9992	0.9989	0.9988	0.9983	0.9983	0.9982	0.9980	0.9979	0.9979	0.9977	0.9977	0.9977
0.71	0.9991	0.9988	0.9987	0.9982	0.9981	0.9981	0.9978	0.9977	0.9977	0.9975	0.9974	0.9974
0.72	0.9991	0.9987	0.9986	0.9980	0.9979	0.9979	0.9976	0.9975	0.9975	0.9973	0.9972	0.9972
0.73	0.9990	0.9986	0.9985	0.9978	0.9977	0.9977	0.9973	0.9973	0.9972	0.9970	0.9970	0.9969
0.74	0.9989	0.9985	0.9983	0.9977	0.9975	0.9975	0.9971	0.9970	0.9970	0.9968	0.9967	0.9967
0.75	0.9988	0.9984	0.9982	0.9975	0.9973	0.9973	0.9969	0.9968	0.9968	0.9965	0.9965	0.9964

β	Internal diameter of pipe in inches, D: 16			20			24			30		
	14.688	15.000	15.250	18.814	19.000	19.250	22.626	23.000	23.250	28.628	29.000	29.250
0.10	0.9922	0.9922	0.9921	0.9914	0.9914	0.9913	0.9908	0.9908	0.9907	0.9902	0.9902	0.9901
0.11	0.9931	0.9930	0.9929	0.9923	0.9923	0.9922	0.9918	0.9918	0.9917	0.9913	0.9912	0.9912
0.12	0.9938	0.9937	0.9937	0.9931	0.9931	0.9931	0.9927	0.9927	0.9926	0.9922	0.9922	0.9922
0.13	0.9945	0.9944	0.9944	0.9939	0.9939	0.9938	0.9935	0.9935	0.9934	0.9931	0.9931	0.9930
0.14	0.9951	0.9950	0.9950	0.9945	0.9945	0.9945	0.9942	0.9942	0.9942	0.9939	0.9938	0.9938
0.15	0.9955	0.9955	0.9955	0.9951	0.9951	0.9951	0.9949	0.9948	0.9948	0.9946	0.9945	0.9945
0.16	0.9961	0.9960	0.9960	0.9957	0.9957	0.9956	0.9954	0.9954	0.9954	0.9952	0.9951	0.9951
0.17	0.9965	0.9964	0.9964	0.9961	0.9961	0.9961	0.9959	0.9959	0.9959	0.9957	0.9957	0.9957
0.18	0.9968	0.9968	0.9968	0.9965	0.9965	0.9965	0.9963	0.9963	0.9963	0.9962	0.9961	0.9961
0.19	0.9971	0.9971	0.9971	0.9969	0.9969	0.9959	0.9967	0.9967	0.9967	0.9965	0.9965	0.9965
0.20	0.9974	0.9974	0.9973	0.9972	0.9971	0.9971	0.9970	0.9970	0.9970	0.9969	0.9969	0.9969
0.21	0.9976	0.9976	0.9976	0.9974	0.9974	0.9974	0.9973	0.9973	0.9972	0.9971	0.9971	0.9971
0.22	0.9978	0.9978	0.9977	0.9976	0.9976	0.9976	0.9975	0.9975	0.9975	0.9974	0.9973	0.9973
0.23	0.9979	0.9979	0.9979	0.9977	0.9977	0.9977	0.9976	0.9976	0.9976	0.9975	0.9975	0.9975
0.24	0.9980	0.9980	0.9980	0.9979	0.9979	0.9978	0.9978	0.9978	0.9977	0.9977	0.9977	0.9977
0.25	0.9981	0.9981	0.9981	0.9980	0.9980	0.9980	0.9979	0.9979	0.9979	0.9978	0.9978	0.9978
0.26	0.9982	0.9982	0.9982	0.9981	0.9981	0.9980	0.9980	0.9980	0.9980	0.9979	0.9979	0.9979
0.27	0.9983	0.9983	0.9983	0.9982	0.9982	0.9981	0.9981	0.9981	0.9981	0.9980	0.9980	0.9980
0.28	0.9984	0.9984	0.9984	0.9983	0.9983	0.9983	0.9982	0.9982	0.9982	0.9981	0.9981	0.9981
0.29	0.9985	0.9985	0.9985	0.9984	0.9984	0.9984	0.9983	0.9983	0.9983	0.9982	0.9982	0.9982
0.30	0.9986	0.9986	0.9985	0.9985	0.9985	0.9985	0.9984	0.9984	0.9984	0.9983	0.9983	0.9983
0.31	0.9987	0.9987	0.9987	0.9986	0.9986	0.9986	0.9985	0.9985	0.9985	0.9984	0.9984	0.9984
0.32	0.9988	0.9988	0.9987	0.9987	0.9987	0.9987	0.9986	0.9986	0.9986	0.9985	0.9985	0.9985
0.33	0.9989	0.9989	0.9988	0.9988	0.9988	0.9988	0.9987	0.9987	0.9987	0.9987	0.9986	0.9986
0.34	0.9990	0.9989	0.9989	0.9989	0.9989	0.9989	0.9988	0.9988	0.9988	0.9988	0.9988	0.9988
0.35	0.9990	0.9990	0.9990	0.9990	0.9990	0.9990	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989
0.36	0.9991	0.9991	0.9991	0.9991	0.9991	0.9990	0.9990	0.9990	0.9990	0.9990	0.9990	0.9990
0.37	0.9992	0.9992	0.9992	0.9991	0.9991	0.9991	0.9991	0.9991	0.9991	0.9991	0.9991	0.9991
0.38	0.9993	0.9993	0.9993	0.9992	0.9992	0.9992	0.9992	0.9992	0.9992	0.9992	0.9992	0.9992
0.39	0.9994	0.9994	0.9994	0.9993	0.9993	0.9993	0.9993	0.9993	0.9993	0.9993	0.9993	0.9993
0.40	0.9994	0.9994	0.9994	0.9994	0.9994	0.9994	0.9994	0.9994	0.9994	0.9993	0.9993	0.9993
0.41	0.9995	0.9995	0.9995	0.9995	0.9995	0.9995	0.9994	0.9994	0.9994	0.9994	0.9994	0.9994
0.42	0.9995	0.9995	0.9996	0.9995	0.9995	0.9995	0.9995	0.9995	0.9995	0.9995	0.9995	0.9995
0.43	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996
0.44	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9995	0.9996	0.9996	0.9996	0.9996	0.9996
0.45	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997
0.46	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997
0.47	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998
0.48	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998
0.49	0.9998	0.9998	0.9998	0.9998	0.9999	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998
0.50	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998
0.51	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998
0.52	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998
0.53	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998
0.54	0.9998	0.9998	0.9998	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997
0.55	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997
0.56	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996
0.57	0.9995	0.9996	0.9995	0.9995	0.9995	0.9995	0.9995	0.9995	0.9995	0.9995	0.9995	0.9995
0.58	0.9995	0.9995	0.9995	0.9994	0.9994	0.9994	0.9994	0.9994	0.9994	0.9994	0.9994	0.9994
0.59	0.9994	0.9994	0.9994	0.9993	0.9993	0.9993	0.9993	0.9993	0.9993	0.9993	0.9993	0.9993
0.60	0.9993	0.9993	0.9993	0.9992	0.9992	0.9992	0.9992	0.9992	0.9992	0.9991	0.9991	0.9991
0.61	0.9992	0.9992	0.9991	0.9991	0.9991	0.9991	0.9990	0.9990	0.9990	0.9990	0.9990	0.9990
0.62	0.9990	0.9990	0.9990	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.9988	0.9988	0.9988
0.63	0.9989	0.9989	0.9989	0.9988	0.9988	0.9988	0.9987	0.9987	0.9987	0.9987	0.9987	0.9987
0.64	0.9987	0.9987	0.9987	0.9986	0.9986	0.9986	0.9985	0.9985	0.9985	0.9985	0.9985	0.9985
0.65	0.9985	0.9985	0.9985	0.9984	0.9984	0.9984	0.9983	0.9983	0.9983	0.9983	0.9983	0.9983
0.66	0.9983	0.9983	0.9983	0.9982	0.9982	0.9982	0.9981	0.9981	0.9981	0.9980	0.9980	0.9980
0.67	0.9981	0.9981	0.9981	0.9980	0.9980	0.9980	0.9979	0.9979	0.9979	0.9978	0.9978	0.9978
0.68	0.9979	0.9979	0.9979	0.9977	0.9977	0.9977	0.9976	0.9976	0.9976	0.9975	0.9975	0.9975
0.69	0.9977	0.9977	0.9977	0.9975	0.9975	0.9975	0.9974	0.9974	0.9974	0.9973	0.9973	0.9973
0.70	0.9975	0.9974	0.9974	0.9972	0.9972	0.9972	0.9971	0.9971	0.9971	0.9970	0.9970	0.9970
0.71	0.9972	0.9972	0.9972	0.9970	0.9970	0.9970	0.9968	0.9968	0.9968	0.9967	0.9967	0.9967
0.72	0.9969	0.9969	0.9969	0.9967	0.9967	0.9967	0.9965	0.9965	0.9965	0.9964	0.9964	0.9964
0.73	0.9967	0.9966	0.9966	0.9964	0.9964	0.9964	0.9962	0.9962	0.9962	0.9961	0.9961	0.9961
0.74	0.9964	0.9964	0.9963	0.9961	0.9961	0.9961	0.9959	0.9959	0.9959	0.9957	0.9957	0.9957
0.75	0.9961	0.9961	0.9961	0.9958	0.9958	0.9958	0.9956	0.9955	0.9956	0.9954	0.9954	0.9954

TABLE 6

Reynolds Number Factor, F_r
"b" Values for Pipe Taps

$$F_r = 1 + \frac{b}{\sqrt{h_w\, p_f}}$$

Orifice Diam., *d*, Inches	Internal Diameter of Pipe, *D*, Inches								
	2			3				4	
	1.689	1.939	2.067	2.300	2.626	2.900	3.068	3.152	3.438
.250	.1105	.1091	.1087	.1081	....	....	....	....	....
.375	.0890	.0878	.0877	.0879	.0888	.0898	.0905	.0908	.0918
.500	.0758	.0734	.0729	.0728	.0737	.0750	.0758	.0763	.0778
.625	.0693	.0647	.0635	.0624	.0624	.0634	.0642	.0646	.0662
.750	.0675	.0608	.0586	.0559	.0546	.0548	.0552	.0555	.0568
.875	.0684	.0602	.0570	.0528	.0497	.0488	.0488	.0489	.0496
1.000	.0702	.0614	.0576	.0522	.0473	.0452	.0445	.0443	.0443
1.125	.0708	.0635	.0595	.0532	.0469	.0435	.0422	.0417	.0407
1.250	....	.0650	.0616	.0552	.0478	.0434	.0414	.0406	.0397
1.375	....	....	.0629	.0574	.0496	.0443	.0418	.0408	.0379
1.500	....	....	....	.0590	.0518	.0460	.0431	.0418	.0382
1.625	....	....	....	....	.0539	.0482	.0450	.0435	.0392
1.750	....	....	....	....	.0553	.0504	.0471	.0456	.0408
1.875	....	....	....	....	....	.0521	.0492	.0477	.0427
2.000	....	....	....	....	....	.0532	.0508	.0495	.0448
2.125	....	....	....	....	....	....	.0519	.0509	.0467
2.250	....	....	....	....	....	....	....	....	.0483
2.375	....	....	....	....	....	....	....	....	.0494

Orifice Diam., *d*, Inches	Internal Diameter of Pipe, *D*, Inches								
	4			6			8		
	3.826	4.026	4.897	5.189	5.761	6.065	7.625	7.981	8.071
.500	.0799	.0810	.0850	....	....	....	....	....	....
.625	.0685	.0697	.0747	.0762	.0789	.0802	....	....	....
.750	.0590	.0602	.0655	.0672	.0703	.0718	....	....	....
.875	.0513	.0524	.0575	.0592	.0625	.0642	.0716	.0730	.0733
1.000	.0453	.0461	.0506	.0523	.0556	.0573	.0652	.0668	.0662
1.125	.0408	.0412	.0448	.0464	.0495	.0512	.0592	.0609	.0613
1.250	.0376	.0377	.0401	.0413	.0442	.0458	.0538	.0555	.0560
1.375	.0358	.0353	.0363	.0373	.0397	.0412	.0489	.0506	.0510
1.500	.0350	.0340	.0334	.0340	.0360	.0372	.0445	.0462	.0466
1.625	.0351	.0336	.0313	.0315	.0329	.0339	.0404	.0421	.0425
1.750	.0358	.0340	.0300	.0298	.0304	.0311	.0369	.0384	.0388
1.875	.0371	.0349	.0293	.0287	.0285	.0290	.0338	.0352	.0355
2.000	.0388	.0363	.0292	.0281	.0273	.0273	.0311	.0323	.0327
2.125	.0407	.0380	.0297	.0281	.0265	.0262	.0288	.0298	.0301
2.250	.0427	.0398	.0305	.0285	.0261	.0258	.0268	.0277	.0280
2.375	.0445	.0417	.0316	.0293	.0262	.0253	.0252	.0259	.0261
2.500	.0460	.0435	.0330	.0304	.0267	.0254	.0239	.0244	.0246
2.625	.0472	.0450	.0345	.0317	.0274	.0258	.0230	.0232	.0233
2.750	....	.0462	.0362	.0331	.0284	.0265	.0224	.0224	.0224
2.875	....	....	.0379	.0347	.0295	.0274	.0220	.0218	.0218
3.000	....	....	.0395	.0364	.0308	.0285	.0219	.0214	.0213
3.125	....	....	.0410	.0380	.0323	.0297	.0220	.0213	.0211
3.250	....	....	.0422	.0394	.0338	.0311	.0223	.0214	.0212
3.375	....	....	.0432	.0406	.0353	.0325	.0228	.0216	.0214
3.500	....	....	....	.0419	.0367	.0339	.0235	.0221	.0218
3.625	....	....	....	.0428	.0381	.0354	.0243	.0227	.0224
3.750	....	....	....	....	.0393	.0367	.0252	.0234	.0230
3.875	....	....	....	....	.0404	.0380	.0262	.0243	.0238
4.000	....	....	....	....	.0413	.0391	.0273	.0252	.0246
4.250	....	....	....	....	....	....	.0296	.0273	.0268
4.500	....	....	....	....	....	....	.0321	.0296	.0290
4.750	....	....	....	....	....	....	.0344	.0320	.0314
5.000	....	....	....	....	....	....	.0364	.0342	.0336
5.250	....	....	....	....	....	....	.0381	.0361	.0356
5.500	....	....	....	....	....	....	....	.0377	.0372

Orifice Diam., *d*, Inches	Internal Diameter of Pipe, *D*, Inches								
	10			12			16		
	9.564	10.020	10.136	11.376	11.938	12.090	14.688	15.000	15.250
1.000	.0728	....	....	....	....	....	....	....	....
1.125	.0674	.0690	.0694	....	....	....	....	....	....
1.250	.0624	.0641	.0646	.0687	.0704	.0708	....	....	....
1.375	.0576	.0594	.0599	.0643	.0661	.0666	....	....	....
1.500	.0532	.0550	.0555	.0601	.0620	.0625	.0697	.0705	....
1.625	.0490	.0509	.0514	.0561	.0580	.0585	.0662	.0670	.0676
1.750	.0452	.0471	.0476	.0523	.0543	.0548	.0628	.0636	.0642
1.875	.0417	.0436	.0440	.0488	.0508	.0513	.0594	.0603	.0610
2.000	.0385	.0403	.0407	.0454	.0475	.0480	.0563	.0572	.0578
2.125	.0355	.0372	.0377	.0423	.0443	.0449	.0532	.0541	.0548
2.250	.0329	.0345	.0349	.0394	.0414	.0419	.0503	.0512	.0519
2.375	.0305	.0320	.0324	.0367	.0387	.0392	.0475	.0484	.0492
2.500	.0283	.0298	.0301	.0342	.0361	.0366	.0449	.0458	.0466
2.625	.0265	.0277	.0281	.0319	.0337	.0342	.0424	.0433	.0440
2.750	.0248	.0260	.0262	.0298	.0316	.0320	.0400	.0409	.0417
2.875	.0234	.0244	.0246	.0279	.0295	.0300	.0378	.0387	.0394
3.000	.0222	.0230	.0232	.0262	.0277	.0281	.0356	.0365	.0372
3.125	.0212	.0218	.0220	.0244	.0260	.0264	.0336	.0345	.0352
3.250	.0204	.0209	.0210	.0232	.0245	.0249	.0317	.0326	.0332
3.375	.0199	.0201	.0202	.0220	.0232	.0235	.0300	.0308	.0314
3.500	.0196	.0195	.0196	.0210	.0220	.0222	.0283	.0291	.0297
3.625	.0193	.0191	.0191	.0200	.0209	.0212	.0268	.0275	.0281
3.750	.0192	.0188	.0188	.0193	.0200	.0202	.0254	.0261	.0267
3.875	.0193	.0187	.0186	.0187	.0192	.0194	.0240	.0247	.0253
4.000	.0195	.0187	.0186	.0182	.0185	.0187	.0228	.0235	.0240
4.250	.0203	.0192	.0189	.0176	.0176	.0177	.0207	.0213	.0217
4.500	.0215	.0200	.0197	.0175	.0172	.0171	.0190	.0194	.0198
4.750	.0230	.0212	.0208	.0178	.0171	.0170	.0176	.0180	.0182
5.000	.0248	.0228	.0223	.0185	.0174	.0173	.0166	.0168	.0170
5.250	.0267	.0244	.0239	.0194	.0181	.0178	.0160	.0161	.0162
5.500	.0287	.0263	.0257	.0207	.0190	.0186	.0156	.0156	.0156
5.750	.0307	.0282	.0276	.0221	.0202	.0197	.0155	.0154	.0153
6.000	.0326	.0302	.0295	.0231	.0215	.0210	.0157	.0154	.0153
6.250	.0343	.0320	.0316	.0253	.0230	.0224	.0161	.0157	.0154
6.500	.0358	.0336	.0331	.0270	.0246	.0239	.0167	.0162	.0159
6.750	....	.0351	.0346	.0288	.0262	.0256	.0174	.0169	.0164
7.000	....	.0363	.0359	.0304	.0279	.0272	.0184	.0177	.0172
7.250	....	....	....	.0320	.0295	.0288	.0195	.0187	.0181
7.500	....	....	....	.0334	.0310	.0304	.0206	.0198	.0191
7.750	....	....	....	.0347	.0325	.0318	.0219	.0209	.0202
8.000	....	....	....	....	.0338	.0332	.0232	.0222	.0214
8.250	....	....	....	....	.0349	.0344	.0246	.0235	.0227
8.500	....	....	....	....	....	....	.0259	.0248	.0240
8.750	....	....	....	....	....	....	.0273	.0262	.0253
9.000	....	....	....	....	....	....	.0286	.0276	.0267
9.250	....	....	....	....	....	....	.0299	.0288	.0280
9.500	....	....	....	....	....	....	.0311	.0300	.0292
9.750	....	....	....	....	....	....	.0322	.0312	.0304
10.000	....	....	....	....	....	....	.0332	.0323	.0315
10.250	....	....	....	....	....	....	.0341	.0333	.0326
10.500	....	....	....	....	....	....	....	.0341	.0335

Orifice Diam., *d*, Inches	Internal Diameter of Pipe, *D*, Inches								
	20			24			30		
	18.814	19.000	19.250	22.626	23.000	23.250	28.628	29.000	29.250
2.000	.0563	.0667	.0672	....	....	....	....	....	....
2.125	.0535	.0539	.0544	....	....	....	....	....	....
2.250	.0609	.0613	.0618	....	....	....	....	....	....
2.375	.0583	.0588	.0593	.0658	.0665	.0669	....	....	....
2.500	.0558	.0562	.0568	.0635	.0642	.0646	....	....	....
2.625	.0534	.0539	.0544	.0613	.0620	.0624	....	....	....
2.750	.0510	.0515	.0520	.0591	.0598	.0603	....	....	....
2.875	.0488	.0492	.0498	.0570	.0577	.0582	.0667	....	....
3.000	.0466	.0470	.0476	.0549	.0556	.0561	.0649	.0654	.0657
3.125	.0445	.0449	.0455	.0529	.0536	.0541	.0630	.0636	.0639
3.250	.0425	.0429	.0435	.0509	.0516	.0521	.0613	.0616	.0622
3.375	.0406	.0410	.0416	.0490	.0497	.0502	.0595	.0601	.0604
3.500	.0387	.0391	.0397	.0471	.0479	.0484	.0578	.0584	.0587
3.625	.0369	.0373	.0379	.0454	.0461	.0466	.0561	.0567	.0571
3.750	.0352	.0356	.0362	.0436	.0444	.0449	.0545	.0550	.0554
3.875	.0336	.0340	.0346	.0419	.0427	.0432	.0528	.0534	.0538
4.000	.0320	.0324	.0330	.0403	.0411	.0416	.0513	.0518	.0522
4.250	.0291	.0295	.0301	.0372	.0380	.0385	.0482	.0488	.0492
4.500	.0265	.0269	.0274	.0343	.0351	.0356	.0453	.0459	.0463
4.750	.0242	.0246	.0250	.0316	.0324	.0328	.0425	.0431	.0435
5.000	.0221	.0225	.0229	.0292	.0299	.0303	.0399	.0405	.0409
5.250	.0203	.0206	.0210	.0269	.0276	.0280	.0374	.0380	.0384
5.500	.0188	.0190	.0194	.0248	.0255	.0259	.0350	.0356	.0360
5.750	.0175	.0177	.0180	.0230	.0236	.0240	.0328	.0334	.0338
6.000	.0164	.0165	.0168	.0212	.0218	.0222	.0307	.0313	.0317
6.250	.0155	.0156	.0158	.0197	.0202	.0206	.0287	.0293	.0297
6.500	.0148	.0149	.0150	.0184	.0189	.0192	.0269	.0274	.0278
6.750	.0143	.0144	.0145	.0172	.0176	.0179	.0252	.0257	.0260
7.000	.0141	.0141	.0141	.0162	.0166	.0168	.0236	.0241	.0244
7.250	.0140	.0140	.0139	.0153	.0156	.0158	.0221	.0226	.0229
7.500	.0140	.0140	.0139	.0145	.0148	.0150	.0207	.0212	.0215
7.750	.0142	.0141	.0140	.0140	.0142	.0144	.0195	.0199	.0202
8.000	.0145	.0144	.0142	.0136	.0138	.0138	.0183	.0187	.0190
8.250	.0151	.0148	.0145	.0133	.0134	.0132	.0173	.0177	.0179
8.500	.0155	.0154	.0151	.0132	.0132	.0130	.0164	.0167	.0169
8.750	.0163	.0160	.0157	.0131	.0130	.0130	.0155	.0158	.0161
9.000	.0171	.0168	.0163	.0131	.0130	.0130	.0148	.0151	.0153
9.250	.0180	.0176	.0171	.0133	.0131	.0130	.0142	.0144	.0146
9.500	.0189	.0185	.0180	.0136	.0133	.0132	.0136	.0138	.0140
9.750	.0198	.0194	.0189	.0139	.0136	.0134	.0132	.0133	.0134
10.000	.0209	.0204	.0198	.0143	.0140	.0138	.0128	.0129	.0130
10.250	.0219	.0214	.0208	.0148	.0144	.0142	.0125	.0126	.0127
10.500	.0230	.0225	.0219	.0154	.0150	.0147	.0123	.0124	.0124
10.750	.0241	.0235	.0229	.0160	.0155	.0152	.0122	.0122	.0122
11.000	.0252	.0247	.0240	.0168	.0162	.0158	.0121	.0121	.0121
11.250	.0253	.0261	.0251	.0175	.0169	.0165	.0122	.0121	.0121
11.500	.0273	.0268	.0262	.0183	.0176	.0172	.0122	.0121	.0122
11.750	.0284	.0278	.0272	.0191	.0184	.0180	.0124	.0123	.0122
12.000	.0293	.0288	.0282	.0200	.0192	.0190	.0126	.0124	.0123
12.500	.0312	.0307	.0301	.0218	.0210	.0204	.0132	.0130	.0128
13.000	.0327	.0323	.0318	.0236	.0228	.0222	.0140	.0137	.0135
13.500	....	....	....	.0254	.0246	.0240	.0150	.0146	.0143
14.000	....	....	....	.0272	.0264	.0258	.0161	.0156	.0153
14.500	....	....	....	.0289	.0280	.0275	.0173	.0168	.0165
15.000	....	....	....	.0304	.0296	.0291	.0186	.0181	.0177
15.500	....	....	....	.0318	.0311	.0306	.0200	.0194	.0190
16.000	....	....	....	....	.0323	.0318	.0215	.0209	.0204
16.500	....	....	....	....	....	....	.0230	.0223	.0219
17.000	....	....	....	....	....	....	.0244	.0238	.0233
17.500	....	....	....	....	....	....	.0259	.0252	.0248
18.000	....	....	....	....	....	....	.0272	.0266	.0261
18.500	....	....	....	....	....	....	.0286	.0279	.0275
19.000	....	....	....	....	....	....	.0298	.0292	.0288
19.500	....	....	....	....	....	....	.0309	.0303	.0299
20.000	....	....	....	....	....	....	.0318	.0313	.0310

TABLE 6-A

Reynolds Number Factor, F_r
"b" Values for Pipe Taps

$$F_r = 1 + \frac{b}{\sqrt{h_w\, p_f}}$$

Internal Diameter of Pipe, *D*, inches

β	2			3				4			
	1.689	1.939	2.067	2.300	2.626	2.900	3.068	3.152	3.438	3.826	4.026
0.10	0.1295	0.1209	0.1173	0.1118	0.1058	0.1017	0.0996	0.0986	0.0957	0.0924	0.0909
0.11	0.1252	0.1167	0.1132	0.1077	0.1016	0.0976	0.0954	0.0945	0.0915	0.0882	0.0867
0.12	0.1212	0.1125	0.1090	0.1035	0.0975	0.0934	0.0913	0.0903	0.0874	0.0841	0.0826
0.13	0.1172	0.1086	0.1051	0.0996	0.0935	0.0895	0.0874	0.0864	0.0835	0.0802	0.0787
0.14	0.1134	0.1049	0.1013	0.0958	0.0898	0.0858	0.0837	0.0827	0.0797	0.0765	0.0750
0.15	0.1098	0.1013	0.0978	0.0923	0.0863	0.0823	0.0801	0.0792	0.0762	0.0729	0.0715
0.16	0.1055	0.0980	0.0944	0.0889	0.0829	0.0789	0.0768	0.0758	0.0729	0.0696	0.0682
0.17	0.1033	0.0948	0.0912	0.0855	0.0798	0.0758	0.0737	0.0727	0.0698	0.0665	0.0650
0.18	0.1001	0.0916	0.0881	0.0827	0.0767	0.0727	0.0706	0.0696	0.0667	0.0634	0.0620
0.19	0.0973	0.0888	0.0853	0.0799	0.0739	0.0699	0.0678	0.0669	0.0639	0.0607	0.0592
0.20	0.0945	0.0861	0.0825	0.0771	0.0712	0.0672	0.0651	0.0642	0.0613	0.0580	0.0566
0.21	0.0919	0.0835	0.0800	0.0746	0.0687	0.0647	0.0626	0.0617	0.0588	0.0555	0.0541
0.22	0.0894	0.0811	0.0776	0.0722	0.0563	0.0623	0.0603	0.0593	0.0564	0.0532	0.0518
0.23	0.0872	0.0788	0.0753	0.0700	0.0641	0.0602	0.0581	0.0571	0.0543	0.0510	0.0496
0.24	0.0851	0.0767	0.0733	0.0679	0.0621	0.0581	0.0561	0.0551	0.0523	0.0490	0.0476
0.25	0.0831	0.0748	0.0714	0.0660	0.0602	0.0563	0.0542	0.0533	0.0504	0.0472	0.0458
0.26	0.0812	0.0730	0.0595	0.0642	0.0584	0.0545	0.0524	0.0515	0.0487	0.0455	0.0441
0.27	0.0796	0.0713	0.0579	0.0626	0.0558	0.0530	0.0509	0.0500	0.0471	0.0440	0.0426
0.28	0.0781	0.0599	0.0565	0.0512	0.0554	0.0516	0.0495	0.0486	0.0458	0.0426	0.0412
0.29	0.0766	0.0685	0.0651	0.0598	0.0541	0.0502	0.0482	0.0473	0.0445	0.0413	0.0399
0.30	0.0753	0.0672	0.0638	0.0586	0.0529	0.0490	0.0470	0.0461	0.0433	0.0401	0.0388
0.31	0.0741	0.0661	0.0627	0.0575	0.0518	0.0480	0.0460	0.0451	0.0423	0.0391	0.0378
0.32	0.0730	0.0650	0.0616	0.0564	0.0508	0.0470	0.0450	0.0441	0.0413	0.0382	0.0368
0.33	0.0720	0.0640	0.0606	0.0555	0.0499	0.0461	0.0441	0.0432	0.0405	0.0374	0.0360
0.34	0.0712	0.0632	0.0599	0.0548	0.0492	0.0455	0.0435	0.0426	0.0398	0.0368	0.0354
0.35	0.0705	0.0623	0.0593	0.0542	0.0486	0.0449	0.0429	0.0420	0.0393	0.0362	0.0349
0.36	0.0699	0.0620	0.0587	0.0537	0.0481	0.0444	0.0424	0.0416	0.0388	0.0358	0.0345
0.37	0.0693	0.0615	0.0582	0.0532	0.0477	0.0440	0.0421	0.0412	0.0385	0.0355	0.0341
0.38	0.0689	0.0611	0.0578	0.0529	0.0474	0.0437	0.0418	0.0409	0.0382	0.0352	0.0339
0.39	0.0684	0.0507	0.0575	0.0525	0.0471	0.0435	0.0415	0.0407	0.0380	0.0350	0.0337
0.40	0.0581	0.0504	0.0572	0.0523	0.0469	0.0433	0.0414	0.0405	0.0379	0.0349	0.0336
0.41	0.0578	0.0503	0.0571	0.0522	0.0468	0.0432	0.0414	0.0405	0.0379	0.0349	0.0336
0.42	0.0677	0.0502	0.0570	0.0521	0.0458	0.0433	0.0414	0.0405	0.0379	0.0350	0.0337
0.43	0.0576	0.0501	0.0570	0.0522	0.0469	0.0434	0.0415	0.0402	0.0381	0.0352	0.0339
0.44	0.0575	0.0301	0.0570	0.0522	0.0470	0.0435	0.0417	0.0408	0.0382	0.0354	0.0341
0.45	0.0575	0.0502	0.0571	0.0524	0.0472	0.0437	0.0419	0.0410	0.0385	0.0357	0.0344
0.46	0.0576	0.0503	0.0572	0.0525	0.0474	0.0440	0.0422	0.0413	0.0388	0.0360	0.0347
0.47	0.0576	0.0504	0.0574	0.0528	0.0476	0.0442	0.0424	0.0416	0.0391	0.0363	0.0351
0.48	0.0577	0.0506	0.0576	0.0530	0.0479	0.0446	0.0428	0.0420	0.0395	0.0367	0.0355
0.49	0.0578	0.0608	0.0578	0.0532	0.0482	0.0449	0.0431	0.0423	0.0399	0.0372	0.0359
0.50	0.0680	0.0611	0.0581	0.0535	0.0485	0.0453	0.0436	0.0428	0.0404	0.0377	0.0365
0.51	0.0682	0.0613	0.0584	0.0539	0.0490	0.0458	0.0440	0.0433	0.0409	0.0382	0.0370
0.52	0.0684	0.0615	0.0587	0.0543	0.0494	0.0462	0.0445	0.0437	0.0413	0.0387	0.0375
0.53	0.0687	0.0619	0.0590	0.0547	0.0499	0.0467	0.0450	0.0442	0.0419	0.0393	0.0381
0.54	0.0689	0.0522	0.0594	0.0551	0.0503	0.0472	0.0455	0.0448	0.0424	0.0398	0.0387
0.55	0.0692	0.0625	0.0598	0.0555	0.0508	0.0477	0.0460	0.0453	0.0430	0.0404	0.0393
0.56	0.0694	0.0528	0.0501	0.0559	0.0513	0.0482	0.0466	0.0458	0.0435	0.0410	0.0399
0.57	0.0595	0.0532	0.0305	0.0563	0.0517	0.0487	0.0471	0.0464	0.0441	0.0416	0.0405
0.58	0.0599	0.0635	0.0508	0.0557	0.0522	0.0492	0.0476	0.0469	0.0447	0.0422	0.0412
0.59	0.0701	0.0638	0.0612	0.0571	0.0527	0.0497	0.0482	0.0474	0.0453	0.0428	0.0418
0.60	0.0704	0.0641	0.0615	0.0575	0.0532	0.0502	0.0487	0.0480	0.0458	0.0434	0.0424
0.61	0.0705	0.0643	0.0618	0.0578	0.0535	0.0506	0.0491	0.0484	0.0463	0.0439	0.0429
0.62	0.0706	0.0645	0.0620	0.0581	0.0539	0.0510	0.0495	0.0489	0.0468	0.0444	0.0434
0.63	0.0707	0.0648	0.0623	0.0585	0.0543	0.0515	0.0500	0.0493	0.0473	0.0450	0.0440
0.64	0.0708	0.0649	0.0625	0.0587	0.0546	0.0518	0.0504	0.0497	0.0477	0.0454	0.0444
0.65	0.0709	0.0651	0.0627	0.0590	0.0549	0.0522	0.0508	0.0501	0.0481	0.0459	0.0449
0.66	0.0708	0.0651	0.0628	0.0591	0.0551	0.0525	0.0511	0.0504	0.0485	0.0463	0.0453
0.67	0.0708	0.0653	0.0629	0.0594	0.0554	0.0528	0.0514	0.0508	0.0489	0.0467	0.0458
0.68	0.0708	0.0653	0.0630	0.0595	0.0556	0.0531	0.0517	0.0511	0.0492	0.0471	0.0462
0.69	0.0705	0.0652	0.0629	0.0595	0.0557	0.0532	0.0518	0.0512	0.0494	0.0473	0.0464
0.70	0.0704	0.0651	0.0629	0.0595	0.0558	0.0533	0.0520	0.0514	0.0496	0.0476	0.0467

Internal Diameter of Pipe, *D*, inches

β	6				8			10			12		
	4.897	5.189	5.761	6.065	7.625	7.981	8.071	9.564	10.020	10.136	11.376	11.938	12.090
0.10	0.0859	0.0846	0.0825	0.0815	0.0777	0.0771	0.0769	0.0747	0.0742	0.0741	0.0729	0.0724	0.0725
0.11	0.0818	0.0805	0.0783	0.0773	0.0736	0.0729	0.0727	0.0706	0.0700	0.0699	0.0687	0.0682	0.0681
0.12	0.0777	0.0764	0.0742	0.0732	0.0695	0.0688	0.0687	0.0665	0.0660	0.0658	0.0646	0.0642	0.0640
0.13	0.0738	0.0725	0.0703	0.0694	0.0656	0.0649	0.0648	0.0626	0.0621	0.0619	0.0607	0.0603	0.0602
0.14	0.0701	0.0688	0.0666	0.0657	0.0619	0.0612	0.0611	0.0589	0.0584	0.0583	0.0571	0.0566	0.0565
0.15	0.0666	0.0653	0.0631	0.0622	0.0584	0.0578	0.0576	0.0554	0.0549	0.0548	0.0536	0.0531	0.0530
0.16	0.0633	0.0620	0.0598	0.0589	0.0551	0.0545	0.0543	0.0522	0.0516	0.0515	0.0503	0.0498	0.0497
0.17	0.0601	0.0589	0.0567	0.0558	0.0520	0.0514	0.0512	0.0491	0.0485	0.0484	0.0472	0.0467	0.0466
0.18	0.0571	0.0558	0.0537	0.0527	0.0490	0.0484	0.0482	0.0461	0.0455	0.0454	0.0442	0.0438	0.0436
0.19	0.0544	0.0531	9.0510	0.0500	0.0463	0.0456	0.0455	0.0433	0.0428	0.0427	0.0415	0.0410	0.0409
0.20	0.0517	0.0504	0.0483	0.0474	0.0436	0.0430	0.0428	0.0407	0.0402	0.0401	0.0389	0.0384	0.0383
0.21	0.0492	0.0480	0.0459	0.0449	0.0412	0.0405	0.0404	0.0383	0.0377	0.0376	0.0364	0.0360	0.0359
0.22	0.0469	0.0457	0.0436	0.0426	0.0389	0.0383	0.0381	0.0360	0.0355	0.0353	0.0342	0.0337	0.0336
0.23	0.0448	0.0435	0.0414	0.0405	0.0368	0.0362	0.0360	0.0339	0.0334	0.0333	0.0321	0.0316	0.0315
0.24	0.0428	0.0416	0.0395	0.0385	0.0349	0.0342	0.0341	0.0320	0.0314	0.0313	0.0302	0.0297	0.0296
0.25	0.0410	0.0398	0.0377	0.0367	0.0331	0.0324	0.0323	0.0302	0.0297	0.0296	0.0284	0.0279	0.0278
0.26	0.0393	0.0381	0.0360	0.0350	0.0314	0.0308	0.0306	0.0285	0.0280	0.0279	0.0267	0.0263	0.0262
0.27	0.0378	0.0366	0.0345	0.0336	0.0299	0.0293	0.0292	0.0271	0.0266	0.0264	0.0253	0.0248	0.0247
0.28	0.0365	0.0352	0.0332	0.0322	0.0286	0.0280	0.0278	0.0258	0.0252	0.0251	0.0240	0.0235	0.0234
0.29	0.0352	0.0340	0.0319	0.0310	0.0274	0.0268	0.0266	0.0245	0.0240	0.0239	0.0228	0.0223	0.0222
0.30	0.0341	0.0328	0.0308	0.0299	0.0263	0.0257	0.0255	0.0235	0.0230	0.0228	0.0217	0.0213	0.0211
0.31	0.0331	0.0319	0.0298	0.0289	0.0254	0.0247	0.0246	0.0225	0.0220	0.0219	0.0208	0.0203	0.0202
0.32	0.0322	0.0310	0.0290	0.0280	0.0245	0.0239	0.0237	0.0217	0.0212	0.0211	0.0199	0.0195	0.0194
0.33	0.0314	0.0302	0.0282	0.0273	0.0238	0.0232	0.0230	0.0210	0.0205	0.0204	0.0192	0.0188	0.0187
0.34	0.0308	0.0296	0.0276	0.0267	0.0232	0.0226	0.0225	0.0204	0.0199	0.0198	0.0187	0.0183	0.0182
0.35	0.0303	0.0291	0.0272	0.0263	0.0228	0.0221	0.0220	0.0200	0.0195	0.0194	0.0183	0.0178	0.0177
0.36	0.0299	0.0287	0.0268	0.0259	0.0224	0.0218	0.0216	0.0196	0.0192	0.0190	0.0179	0.0175	0.0174
0.37	0.0296	0.0284	0.0265	0.0256	0.0221	0.0215	0.0214	0.0194	0.0189	0.0188	0.0177	0.0173	0.0172
0.38	0.0294	0.0282	0.0263	0.0254	0.0220	0.0214	0.0212	0.0193	0.0188	0.0187	0.0176	0.0171	0.0170
0.39	0.0293	0.0281	0.0262	0.0253	0.0219	0.0213	0.0211	0.0192	0.0187	0.0186	0.0175	0.0171	0.0170
0.40	0.0292	0.0281	0.0261	0.0253	0.0219	0.0213	0.0212	0.0192	0.0187	0.0186	0.0175	0.0171	0.0170
0.41	0.0292	0.0281	0.0262	0.0253	0.0220	0.0214	0.0213	0.0193	0.0189	0.0187	0.0177	0.0173	0.0172
0.42	0.0294	0.0282	0.0263	0.0255	0.0222	0.0216	0.0214	0.0195	0.0191	0.0189	0.0179	0.0175	0.0174
0.43	0.0296	0.0285	0.0266	0.0257	0.0224	0.0218	0.0217	0.0198	0.0193	0.0192	0.0182	0.0178	0.0177
0.44	0.0298	0.0287	0.0268	0.0260	0.0227	0.0221	0.0220	0.0201	0.0197	0.0196	0.0185	0.0181	0.0180
0.45	0.0301	0.0290	0.0272	0.0263	0.0231	0.0225	0.0224	0.0205	0.0201	0.0200	0.0189	0.0185	0.0184
0.46	0.0305	0.0294	0.0276	0.0268	0.0235	0.0230	0.0228	0.0210	0.0205	0.0204	0.0194	0.0190	0.0189
0.47	0.0309	0.0298	0.0280	0.0272	0.0240	0.0235	0.0233	0.0215	0.0210	0.0209	0.0199	0.0195	0.0194
0.48	0.0314	0.0303	0.0285	0.0277	0.0245	0.0240	0.0238	0.0220	0.0216	0.0215	0.0205	0.0201	0.0200
0.49	0.0319	0.0308	0.0290	0.0282	0.0251	0.0245	0.0244	0.0226	0.0222	0.0221	0.0211	0.0207	0.0206
0.50	0.0324	0.0314	0.0296	0.0288	0.0257	0.0252	0.0250	0.0233	0.0228	0.0227	0.0217	0.0213	0.0212
0.51	0.0330	0.0319	0.0302	0.0294	0.0263	0.0258	0.0257	0.0239	0.0235	0.0234	0.0224	0.0220	0.0219
0.52	0.0335	0.0325	0.0308	0.0300	0.0270	0.0265	0.0263	0.0246	0.0242	0.0241	0.0231	0.0227	0.0226
0.53	0.0342	0.0332	0.0315	0.0307	0.0277	0.0272	0.0270	0.0253	0.0249	0.0248	0.0238	0.0235	0.0234
0.54	0.0348	0.0338	0.0321	0.0314	0.0284	0.0279	0.0278	0.0261	0.0256	0.0255	0.0246	0.0242	0.0241
0.55	0.0355	0.0345	0.0328	0.0321	0.0291	0.0286	0.0285	0.0268	0.0264	0.0263	0.0254	0.0250	0.0249
0.56	0.0361	0.0351	0.0335	0.0327	0.0298	0.0293	0.0292	0.0276	0.0272	0.0271	0.0261	0.0258	0.0257
0.57	0.0368	0.0358	0.0342	0.0335	0.0306	0.0301	0.0300	0.0283	0.0279	0.0278	0.0269	0.0266	0.0265
0.58	0.0375	0.0365	0.0349	0.0342	0.0313	0.0309	0.0307	0.0291	0.0287	0.0286	0.0277	0.0274	0.0273
0.59	0.0381	0.0372	0.0356	0.0349	0.0321	0.0316	0.0315	0.0299	0.0295	0.0294	0.0285	0.0282	0.0281
0.60	0.0388	0.0378	0.0363	0.0356	0.0328	0.0323	0.0322	0.0307	0.0303	0.0302	0.0293	0.0290	0.0289
0.61	0.0393	0.0384	0.0369	0.0362	0.0335	0.0330	0.0329	0.0314	0.0310	0.0309	0.0300	0.0297	0.0296
0.62	0.0399	0.0390	0.0375	0.0368	0.0342	0.0337	0.0336	0.0321	0.0317	0.0316	0.0307	0.0304	0.0303
0.63	0.0405	0.0396	0.0381	0.0375	0.0348	0.0344	0.0343	0.0328	0.0324	0.0323	0.0315	0.0311	0.0311
0.64	0.0411	0.0402	0.0387	0.0381	0.0355	0.0350	0.0349	0.0334	0.0331	0.0330	0.0322	0.0318	0.0318
0.65	0.0416	0.0407	0.0393	0.0386	0.0361	0.0357	0.0355	0.0341	0.0337	0.0336	0.0328	0.0325	0.0324
0.66	0.0421	0.0412	0.0398	0.0391	0.0366	0.0362	0.0361	0.0347	0.0343	0.0342	0.0334	0.0331	0.0331
0.67	0.0425	0.0417	0.0403	0.0397	0.0372	0.0368	0.0367	0.0352	0.0349	0.0349	0.0341	0.0338	0.0337
0.68	0.0430	0.0422	0.0408	0.0402	0.0377	0.0373	0.0372	0.0358	0.0355	0.0354	0.0346	0.0344	0.0343
0.69	0.0433	0.0425	0.0411	0.0405	0.0381	0.0377	0.0376	0.0363	0.0359	0.0359	0.0351	0.0348	0.0347
0.70	0.0436	0.0428	0.0415	0.0409	0.0386	0.0382	0.0381	0.0367	0.0364	0.0363	0.0356	0.0353	0.0352

Internal Diameter of Pipe, *D*, inches

β	16			20			24			30		
	14.688	15.000	15.250	18.814	19.000	19.250	22.626	23.000	23.250	28.628	29.000	29.250
0.10	0.0706	0.0705	0.0704	0.0690	0.0689	0.0688	0.0680	0.0679	0.0678	0.0669	0.0669	0.0668
0.11	0.0665	0.0663	0.0662	0.0648	0.0647	0.0647	0.0638	0.0637	0.0637	0.0628	0.0627	0.0627
0.12	0.0624	0.0622	0.0621	0.0607	0.0607	0.0606	0.0597	0.0596	0.0596	0.0587	0.0586	0.0586
0.13	0.0585	0.0584	0.0582	0.0569	0.0568	0.0567	0.0558	0.0558	0.0557	0.0548	0.0548	0.0547
0.14	0.0549	0.0548	0.0546	0.0532	0.0531	0.0530	0.0522	0.0521	0.0520	0.0511	0.0511	0.0511
0.15	0.0514	0.0512	0.0511	0.0497	0.0497	0.0496	0.0487	0.0486	0.0486	0.0477	0.0476	0.0476
0.16	0.0481	0.0479	0.0478	0.0464	0.0464	0.0463	0.0454	0.0453	0.0453	0.0444	0.0443	0.0443
0.17	0.0450	0.0448	0.0447	0.0433	0.0433	0.0432	0.0423	0.0423	0.0422	0.0413	0.0413	0.0412
0.18	0.0420	0.0419	0.0417	0.0404	0.0403	0.0402	0.0394	0.0393	0.0392	0.0383	0.0383	0.0383
0.19	0.0393	0.0391	0.0390	0.0376	0.0376	0.0375	0.0366	0.0366	0.0365	0.0356	0.0356	0.0355
0.20	0.0367	0.0365	0.0364	0.0350	0.0350	0.0349	0.0340	0.0340	0.0339	0.0330	0.0330	0.0329
0.21	0.0343	0.0341	0.0340	0.0326	0.0326	0.0325	0.0316	0.0316	0.0315	0.0306	0.0306	0.0305
0.22	0.0320	0.0318	0.0317	0.0304	0.0303	0.0302	0.0294	0.0293	0.0293	0.0284	0.0283	0.0283
0.23	0.0299	0.0298	0.0296	0.0283	0.0282	0.0281	0.0273	0.0272	0.0272	0.0263	0.0262	0.0262
0.24	0.0280	0.0278	0.0277	0.0264	0.0263	0.0262	0.0254	0.0253	0.0253	0.0244	0.0243	0.0243
0.25	0.0262	0.0261	0.0260	0.0246	0.0246	0.0245	0.0236	0.0236	0.0235	0.0226	0.0226	0.0226
0.26	0.0246	0.0244	0.0243	0.0230	0.0229	0.0228	0.0220	0.0219	0.0219	0.0210	0.0210	0.0209
0.27	0.0231	0.0230	0.0229	0.0215	0.0215	0.0214	0.0206	0.0205	0.0204	0.0196	0.0195	0.0195
0.28	0.0218	0.0217	0.0216	0.0202	0.0202	0.0201	0.0193	0.0192	0.0191	0.0183	0.0182	0.0182
0.29	0.0206	0.0205	0.0204	0.0191	0.0190	0.0189	0.0181	0.0180	0.0180	0.0171	0.0171	0.0170
0.30	0.0196	0.0194	0.0193	0.0180	0.0179	0.0179	0.0170	0.0170	0.0169	0.0161	0.0160	0.0160
0.31	0.0187	0.0185	0.0184	0.0171	0.0170	0.0170	0.0161	0.0161	0.0160	0.0152	0.0151	0.0151
0.32	0.0179	0.0177	0.0176	0.0163	0.0162	0.0162	0.0153	0.0153	0.0152	0.0144	0.0143	0.0143
0.33	0.0172	0.0170	0.0169	0.0156	0.0156	0.0155	0.0147	0.0146	0.0146	0.0137	0.0137	0.0136
0.34	0.0166	0.0165	0.0164	0.0151	0.0150	0.0150	0.0142	0.0141	0.0140	0.0132	0.0131	0.0131
0.35	0.0162	0.0161	0.0160	0.0147	0.0146	0.0145	0.0137	0.0137	0.0136	0.0128	0.0127	0.0127
0.36	0.0159	0.0157	0.0156	0.0144	0.0143	0.0142	0.0134	0.0134	0.0133	0.0125	0.0124	0.0124
0.37	0.0157	0.0155	0.0154	0.0141	0.0141	0.0140	0.0132	0.0132	0.0131	0.0123	0.0122	0.0122
0.38	0.0155	0.0154	0.0153	0.0140	0.0140	0.0139	0.0131	0.0130	0.0130	0.0122	0.0121	0.0121
0.39	0.0155	0.0154	0.0153	0.0140	0.0139	0.0139	0.0131	0.0130	0.0130	0.0122	0.0121	0.0121
0.40	0.0156	0.0154	0.0153	0.0141	0.0140	0.0139	0.0132	0.0131	0.0130	0.0122	0.0122	0.0122
0.41	0.0157	0.0155	0.0154	0.0142	0.0142	0.0141	0.0133	0.0132	0.0132	0.0124	0.0124	0.0123
0.42	0.0159	0.0158	0.0157	0.0144	0.0144	0.0143	0.0136	0.0135	0.0134	0.0126	0.0126	0.0126
0.43	0.0162	0.0161	0.0160	0.0148	0.0147	0.0146	0.0139	0.0138	0.0138	0.0130	0.0129	0.0129
0.44	0.0166	0.0164	0.0163	0.0151	0.0151	0.0150	0.0143	0.0142	0.0141	0.0134	0.0133	0.0133
0.45	0.0170	0.0169	0.0168	0.0156	0.0155	0.0155	0.0147	0.0146	0.0146	0.0138	0.0138	0.0137
0.46	0.0175	0.0174	0.0173	0.0161	0.0160	0.0160	0.0152	0.0151	0.0151	0.0143	0.0143	0.0143
0.47	0.0180	0.0179	0.0178	0.0166	0.0166	0.0165	0.0158	0.0157	0.0157	0.0149	0.0149	0.0148
0.48	0.0186	0.0185	0.0184	0.0172	0.0172	0.0171	0.0164	0.0163	0.0163	0.0155	0.0155	0.0154
0.49	0.0192	0.0191	0.0190	0.0178	0.0178	0.0177	0.0170	0.0169	0.0169	0.0162	0.0161	0.0161
0.50	0.0199	0.0198	0.0197	0.0185	0.0185	0.0184	0.0177	0.0176	0.0176	0.0169	0.0168	0.0168
0.51	0.0206	0.0205	0.0204	0.0193	0.0192	0.0191	0.0184	0.0184	0.0183	0.0176	0.0176	0.0175
0.52	0.0213	0.0212	0.0211	0.0200	0.0199	0.0199	0.0192	0.0191	0.0191	0.0183	0.0183	0.0183
0.53	0.0221	0.0220	0.0219	0.0208	0.0207	0.0207	0.0200	0.0199	0.0199	0.0191	0.0191	0.0191
0.54	0.0229	0.0227	0.0226	0.0215	0.0215	0.0214	0.0208	0.0207	0.0207	0.0199	0.0199	0.0199
0.55	0.0237	0.0235	0.0234	0.0224	0.0223	0.0223	0.0216	0.0215	0.0215	0.0208	0.0207	0.0207
0.56	0.0244	0.0243	0.0242	0.0232	0.0231	0.0231	0.0224	0.0223	0.0223	0.0216	0.0216	0.0215
0.57	0.0253	0.0251	0.0250	0.0240	0.0239	0.0239	0.0232	0.0232	0.0231	0.0224	0.0224	0.0224
0.58	0.0261	0.0260	0.0259	0.0248	0.0248	0.0247	0.0241	0.0240	0.0240	0.0233	0.0233	0.0232
0.59	0.0269	0.0268	0.0267	0.0256	0.0256	0.0255	0.0249	0.0248	0.0248	0.0241	0.0241	0.0241
0.60	0.0277	0.0276	0.0275	0.0265	0.0264	0.0264	0.0257	0.0257	0.0256	0.0250	0.0249	0.0249
0.61	0.0284	0.0283	0.0282	0.0272	0.0272	0.0271	0.0265	0.0265	0.0264	0.0258	0.0257	0.0257
0.62	0.0292	0.0291	0.0290	0.0280	0.0280	0.0279	0.0273	0.0272	0.0272	0.0266	0.0265	0.0265
0.63	0.0299	0.0298	0.0297	0.0288	0.0287	0.0287	0.0281	0.0280	0.0280	0.0273	0.0273	0.0273
0.64	0.0306	0.0305	0.0304	0.0295	0.0295	0.0294	0.0288	0.0288	0.0287	0.0281	0.0281	0.0280
0.65	0.0313	0.0312	0.0312	0.0302	0.0302	0.0301	0.0295	0.0295	0.0294	0.0288	0.0288	0.0288
0.66	0.0320	0.0319	0.0318	0.0309	0.0308	0.0308	0.0302	0.0301	0.0301	0.0295	0.0295	0.0295
0.67	0.0326	0.0325	0.0324	0.0315	0.0315	0.0314	0.0309	0.0308	0.0308	0.0302	0.0302	0.0302
0.68	0.0332	0.0331	0.0330	0.0322	0.0321	0.0321	0.0315	0.0315	0.0314	0.0308	0.0308	0.0308
0.69	0.0337	0.0336	0.0335	0.0327	0.0326	0.0326	0.0320	0.0320	0.0320	0.0314	0.0314	0.0313
0.70	0.0342	0.0341	0.0340	0.0332	0.0332	0.0331	0.0326	0.0325	0.0325	0.0319	0.0319	0.0319

TABLE 7

Expansion Factors — Flange Taps Y_1

Static Pressure Taken from Upstream Taps

h_w/P_{f1} Ratio	$\beta = \frac{d}{D}$ Ratio												
	.1	.2	.3	.4	.45	.50	.52	.54	.56	.58	.60	.61	.62
0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.1	.9989	.9989	.9989	.9988	.9988	.9988	.9988	.9988	.9988	.9988	.9987	.9987	.9987
0.2	.9977	.9977	.9977	.9977	.9976	.9975	.9976	.9976	.9975	.9975	.9975	.9975	.9974
0.3	.9956	.9956	.9956	.9965	.9965	.9964	.9964	.9963	.9963	.9963	.9962	.9962	.9952
0.4	.9954	.9954	.9954	.9953	.9953	.9952	.9952	.9951	.9951	.9950	.9949	.9949	.9949
0.5	.9943	.9943	.9943	.9942	.9941	.9940	.9940	.9939	.9938	.9938	.9937	.9935	.9936
0.6	.9932	.9932	.9931	.9930	.9929	.9928	.9927	.9927	.9926	.9925	.9924	.9924	.9923
0.7	.9920	.9920	.9920	.9919	.9918	.9916	.9915	.9915	.9914	.9913	.9912	.9911	.9910
0.8	.9909	.9909	.9908	.9907	.9906	.9904	.9903	.9902	.9901	.9900	.9899	.9898	.9897
0.9	.9898	.9897	.9897	.9895	.9894	.9892	.9891	.9890	.9889	.9888	.9886	.9885	.9885
1.0	.9886	.9886	.9885	.9884	.9882	.9880	.9879	.9878	.9877	.9875	.9874	.9873	.9872
1.1	.9875	.9875	.9874	.9872	.9870	.9868	.9867	.9866	.9864	.9863	.9861	.9860	.9859
1.2	.9863	.9863	.9862	.9860	.9859	.9856	.9855	.9853	.9852	.9850	.9848	.9847	.9846
1.3	.9852	.9852	.9851	.9849	.9847	.9844	.9843	.9841	.9840	.9838	.9836	.9835	.9833
1.4	.9841	.9840	.9840	.9837	.9835	.9832	.9831	.9829	.9827	.9825	.9823	.9822	.9821
1.5	.9829	.9829	.9828	.9826	.9823	.9820	.9819	.9817	.9815	.9813	.9810	.9809	.9808
1.6	.9818	.9818	.9817	.9814	.9811	.9808	.9806	.9805	.9803	.9800	.9798	.9796	.9795
1.7	.9806	.9806	.9805	.9802	.9800	.9796	.9794	.9792	.9790	.9788	.9785	.9784	.9782
1.8	.9795	.9795	.9794	.9791	.9788	.9784	.9782	.9780	.9778	.9775	.9772	.9771	.9769
1.9	.9784	.9783	.9782	.9779	.9776	.9772	.9770	.9768	.9766	.9763	.9760	.9758	.9756
2.0	.9772	.9772	.9771	.9767	.9764	.9760	.9758	.9756	.9753	.9750	.9747	.9745	.9744
2.1	.9761	.9761	.9759	.9756	.9753	.9748	.9746	.9744	.9741	.9738	.9734	.9733	.9731
2.2	.9750	.9749	.9748	.9744	.9741	.9736	.9734	.9731	.9729	.9725	.9722	.9720	.9718
2.3	.9738	.9738	.9736	.9732	.9729	.9724	.9722	.9719	.9716	.9713	.9709	.9707	.9705
2.4	.9727	.9726	.9725	.9721	.9717	.9712	.9710	.9707	.9704	.9700	.9697	.9694	.9692
2.5	.9715	.9715	.9713	.9709	.9705	.9700	.9698	.9695	.9692	.9688	.9684	.9682	.9680
2.6	.9704	.9704	.9702	.9698	.9594	.9688	.9686	.9683	.9679	.9675	.9671	.9669	.9667
2.7	.9693	.9692	.9691	.9686	.9682	.9676	.9673	.9670	.9667	.9663	.9659	.9656	.9654
2.8	.9681	.9681	.9679	.9674	.9670	.9664	.9661	.9658	.9654	.9650	.9646	.9544	.9641
2.9	.9670	.9669	.9668	.9663	.9658	.9652	.9649	.9646	.9642	.9638	.9633	.9631	.9628
3.0	.9658	.9658	.9656	.9651	.9647	.9640	.9637	.9534	.9630	.9626	.9621	.9618	.9615
3.1	.9647	.9647	.9645	.9639	.9635	.9628	.9625	.9622	.9617	.9613	.9608	.9605	.9603
3.2	.9636	.9635	.9633	.9628	.9623	.9616	.9613	.9609	.9605	.9601	.9595	.9593	.9590
3.3	.9624	.9624	.9522	.9616	.9611	.9604	.9601	.9597	.9593	.9588	.9583	.9580	.9577
3.4	.9613	.9512	.9610	.9604	.9539	.9592	.9589	.9685	.9580	.9576	.9570	.9567	.9564
3.5	.9602	.9501	.9599	.9593	.9588	.9580	.9577	.9573	.9568	.9563	.9558	.9554	.9551
3.6	.9590	.9590	.9587	.9581	.9576	.9568	.9565	.9560	.9556	.9551	.9545	.9542	.9538
3.7	.9579	.9578	.9576	.9570	.9554	.9556	.9553	.9548	.9543	.9538	.9532	.9529	.9526
3.8	.9567	.9567	.9564	.9558	.9552	.9544	.9540	.9536	.9531	.9526	.9520	.9516	.9113
3.9	.9556	.9555	.9553	.9546	.9540	.9532	.9528	.9524	.9519	.9513	.9507	.9504	.9500
4.0	.9545	.9544	.9542	.9535	.9529	.9520	.9516	.9512	.9506	.9501	.9494	.9491	.9487

h_w/P_{f1} Ratio	$\beta = \frac{d}{D}$ Ratio												
	.63	.64	.65	.66	.67	.68	.69	.70	.71	.72	.73	.74	.75
0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.1	.9987	.9987	.9987	.9987	.9987	.9987	.9986	.9986	.9986	.9986	.9986	.9986	.9986
0.2	.9974	.9974	.9974	.9974	.9973	.9973	.9973	.9973	.9972	.9972	.9972	.9971	.9971
0.3	.9961	.9961	.9961	.9960	.9960	.9960	.9959	.9959	.9958	.9958	.9958	.9957	.9957
0.4	.9948	.9948	.9948	.9947	.9947	.9946	.9946	.9945	.9945	.9944	.9943	.9943	.9942
0.5	.9935	.9935	.9934	.9934	.9933	.9933	.9932	.9931	.9931	.9930	.9929	.9929	.9928
0.6	.9923	.9922	.9921	.9921	.9920	.9919	.9918	.9918	.9917	.9916	.9915	.9914	.9913
0.7	.9910	.9909	.9908	.9907	.9907	.9906	.9905	.9904	.9903	.9902	.9901	.9900	.9899
0.8	.9897	.9896	.9895	.9894	.9893	.9892	.9891	.9890	.9889	.9888	.9887	.9886	.9884
0.9	.9884	.9883	.9882	.9881	.9880	.9879	.9878	.9877	.9875	.9874	.9873	.9871	.9870
1.0	.9871	.9870	.9869	.9868	.9867	.9865	.9864	.9863	.9861	.9860	.9859	.9857	.9855
1.1	.9858	.9857	.9856	.9854	.9853	.9852	.9851	.9849	.9848	.9846	.9844	.9843	.9841
1.2	.9845	.9844	.9843	.9841	.9840	.9838	.9837	.9835	.9834	.9832	.9830	.9828	.9826
1.3	.9832	.9831	.9829	.9828	.9827	.9825	.9823	.9822	.9820	.9818	.9816	.9814	.9812
1.4	.9819	.9818	.9816	.9815	.9813	.9812	.9810	.9808	.9806	.9804	.9802	.9800	.9798
1.5	.9806	.9805	.9803	.9802	.9800	.9798	.9796	.9794	.9792	.9790	.9788	.9786	.9783
1.6	.9793	.9792	.9790	.9788	.9787	.9785	.9783	.9781	.9778	.9776	.9774	.9771	.9769
1.7	.9780	.9779	.9777	.9775	.9773	.9771	.9769	.9767	.9764	.9762	.9760	.9757	.9754
1.8	.9768	.9766	.9764	.9762	.9760	.9758	.9755	.9753	.9751	.9748	.9745	.9743	.9740
1.9	.9755	.9753	.9751	.9749	.9747	.9744	.9742	.9739	.9737	.9734	.9731	.9728	.9725
2.0	.9742	.9740	.9738	.9735	.9733	.9731	.9728	.9726	.9723	.9720	.9717	.9714	.9711
2.1	.9729	.9727	.9725	.9722	.9720	.9717	.9715	.9712	.9709	.9706	.9703	.9700	.9696
2.2	.9716	.9714	.9711	.9709	.9706	.9704	.9701	.9698	.9695	.9692	.9689	.9685	.9682
2.3	.9703	.9701	.9698	.9696	.9693	.9690	.9688	.9685	.9681	.9678	.9675	.9671	.9667
2.4	.9690	.9688	.9685	.9683	.9680	.9677	.9674	.9671	.9668	.9664	.9661	.9657	.9653
2.5	.9677	.9675	.9672	.9669	.9666	.9663	.9660	.9657	.9654	.9650	.9646	.9643	.9639
2.6	.9664	.9662	.9659	.9656	.9653	.9650	.9647	.9643	.9640	.9636	.9632	.9628	.9624
2.7	.9651	.9649	.9645	.9643	.9640	.9637	.9633	.9630	.9626	.9622	.9618	.9614	.9610
2.8	.9638	.9636	.9633	.9630	.9626	.9623	.9620	.9616	.9612	.9608	.9604	.9600	.9595
2.9	.9625	.9623	.9620	.9616	.9613	.9610	.9606	.9602	.9598	.9594	.9590	.9585	.9581
3.0	.9613	.9610	.9606	.9603	.9600	.9596	.9592	.9588	.9584	.9580	.9576	.9571	.9566
3.1	.9600	.9597	.9593	.9590	.9586	.9583	.9579	.9575	.9571	.9566	.9562	.9557	.9552
3.2	.9587	.9584	.9580	.9577	.9573	.9569	.9565	.9561	.9557	.9552	.9547	.9542	.9537
3.3	.9574	.9571	.9567	.9564	.9560	.9556	.9552	.9547	.9543	.9538	.9533	.9528	.9523
3.4	.9561	.9558	.9554	.9550	.9546	.9542	.9538	.9534	.9529	.9524	.9519	.9514	.9508
3.5	.9548	.9545	.9541	.9537	.9533	.9529	.9524	.9520	.9515	.9510	.9505	.9500	.9494
3.6	.9535	.9532	.9528	.9524	.9520	.9515	.9511	.9506	.9501	.9496	.9491	.9486	.9480
3.7	.9522	.9518	.9515	.9511	.9506	.9502	.9497	.9492	.9487	.9482	.9477	.9471	.9465
3.8	.9509	.9505	.9502	.9497	.9493	.9488	.9484	.9479	.9474	.9468	.9463	.9457	.9451
3.9	.9496	.9492	.9488	.9484	.9480	.9475	.9470	.9465	.9460	.9454	.9448	.9442	.9436
4.0	.9483	.9479	.9475	.9471	.9466	.9462	.9457	.9451	.9446	.9440	.9434	.9428	.9422

Expansion Factors — Flange Taps Y_m

Static Pressure, Mean of Upstream and Downstream

h_w/P_{fm} Ratio	$\beta = \frac{d}{D}$ Ratio												
	.1	.2	.3	.4	.45	.50	.52	.54	.56	.58	.60	.61	.62
0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.1	.9998	.9998	.9998	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9996	.9996	.9996
0.2	.9995	.9995	.9995	.9995	.9994	.9994	.9994	.9994	.9993	.9993	.9993	.9993	.9992
0.3	.9993	.9993	.9993	.9992	.9992	.9991	.9991	.9990	.9990	.9990	.9989	.9989	.9989
0.4	.9991	.9991	.9990	.9390	.9989	.9988	.9988	.9987	.9987	.9986	.9986	.9985	.9985
0.5	.9988	.9988	.9988	.9987	.9986	.9985	.9985	.9984	.9983	.9983	.9982	.9981	.9981
0.6	.9986	.9986	.9985	.9984	.9984	.9982	.9982	.9981	.9980	.9979	.9978	.9978	.9977
0.7	.9984	.9984	.9983	.9982	.9981	.9979	.9979	.9978	.9977	.9976	.9975	.9974	.9973
0.8	.9981	.9981	.9981	.9979	.9978	.9976	.9976	.9975	.9974	.9972	.9971	.9970	.9970
0.9	.9979	.9979	.9978	.9977	.9975	.9973	.9973	.9972	.9971	.9969	.9968	.9967	.9967
1.0	.9977	.9977	.9976	.9975	.9973	.9971	.9970	.9969	.9968	.9967	.9965	.9964	.9963
1.1	.9975	.9974	.9974	.9972	.9971	.9968	.9967	.9966	.9965	.9963	.9961	.9960	.9959
1.2	.9973	.9973	.9972	.9970	.9968	.9966	.9964	.9963	.9961	.9960	.9958	.9957	.9955
1.3	.9971	.9970	.9970	.9967	.9965	.9963	.9961	.9960	.9958	.9956	.9954	.9953	.9952
1.4	.9968	.9968	.9967	.9965	.9963	.9960	.9958	.9957	.9955	.9953	.9951	.9949	.9948
1.5	.9966	.9966	.9965	.9962	.9960	.9957	.9955	.9954	.9952	.9950	.9948	.9946	.9945
1.6	.9964	.9964	.9962	.9960	.9957	.9954	.9952	.9950	.9948	.9946	.9944	.9943	.9941
1.7	.9962	.9962	.9960	.9958	.9955	.9952	.9950	.9948	.9946	.9943	.9941	.9939	.9938
1.8	.9959	.9959	.9958	.9955	.9953	.9949	.9947	.9945	.9943	.9940	.9937	.9936	.9934
1.9	.9957	.9957	.9956	.9953	.9950	.9948	.9944	.9942	.9940	.9937	.9934	.9933	.9931
2.0	.9955	.9954	.9953	.9950	.9946	.9942	.9940	.9938	.9935	.9932	.9929	.9927	.9925
2.1	.9953	.9953	.9952	.9948	.9945	.9940	.9938	.9936	.9933	.9930	.9927	.9925	.9923
2.2	.9951	.9951	.9950	.9947	.9943	.9938	.9936	.9934	.9931	.9927	.9924	.9922	.9920
2.3	.9949	.9949	.9947	.9944	.9940	.9936	.9933	.9931	.9928	.9924	.9921	.9919	.9917
2.4	.9947	.9947	.9945	.9941	.9938	.9933	.9930	.9927	.9924	.9921	.9917	.9915	.9913
2.5	.9945	.9944	.9943	.9938	.9935	.9930	.9927	.9924	.9921	.9918	.9914	.9912	.9909
2.6	.9943	.9942	.9941	.9936	.9933	.9928	.9925	.9922	.9919	.9915	.9911	.9909	.9907
2.7	.9941	.9941	.9939	.9934	.9930	.9925	.9922	.9919	.9916	.9912	.9907	.9905	.9903
2.8	.9939	.9938	.9937	.9932	.9928	.9922	.9919	.9916	.9913	.9909	.9904	.9902	.9900
2.9	.9937	.9936	.9934	.9929	.9925	.9919	.9916	.9913	.9909	.9905	.9901	.9899	.9896
3.0	.9935	.9934	.9932	.9927	.9923	.9917	.9914	.9911	.9907	.9903	.9898	.9896	.9892
3.1	.9932	.9932	.9930	.9925	.9920	.9914	.9911	.9908	.9904	.9900	.9895	.9892	.9890
3.2	.9931	.9931	.9929	.9923	.9919	.9912	.9909	.9905	.9901	.9897	.9892	.9889	.9886
3.3	.9929	.9928	.9926	.9921	.9916	.9909	.9906	.9902	.9898	.9894	.9889	.9886	.9883
3.4	.9927	.9926	.9924	.9918	.9913	.9907	.9903	.9899	.9895	.9890	.9885	.9882	.9879
3.5	.9925	.9924	.9922	.9916	.9911	.9905	.9901	.9897	.9893	.9888	.9883	.9880	.9877
3.6	.9923	.9923	.9920	.9914	.9909	.9902	.9898	.9894	.9890	.9885	.9878	.9876	.9873
3.7	.9921	.9920	.9918	.9912	.9907	.9899	.9895	.9891	.9887	.9882	.9876	.9873	.9870
3.8	.9919	.9918	.9916	.9910	.9905	.9897	.9893	.9889	.9884	.9879	.9873	.9870	.9866
3.9	.9918	.9917	.9915	.9908	.9902	.9894	.9890	.9886	.9881	.9876	.9870	.9867	.9863
4.0	.9916	.9915	.9913	.9906	.9900	.9892	.9888	.9884	.9879	.9873	.9867	.9864	.9861

h_w/P_{fm} Ratio	$\beta = \frac{d}{D}$ Ratio												
	.63	.64	.65	.66	.67	.68	.69	.70	.71	.72	.73	.74	.75
0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.1	.9996	.9996	.9996	.9996	.9996	.9996	.9995	.9995	.9995	.9995	.9995	.9995	.9995
0.2	.9992	.9992	.9992	.9992	.9991	.9991	.9991	.9991	.9990	.9990	.9990	.9989	.9989
0.3	.9988	.9988	.9988	.9987	.9987	.9987	.9986	.9986	.9986	.9985	.9985	.9984	.9984
0.4	.9984	.9984	.9984	.9983	.9983	.9982	.9982	.9981	.9981	.9980	.9980	.9979	.9978
0.5	.9981	.9980	.9980	.9979	.9978	.9978	.9977	.9977	.9976	.9975	.9974	.9974	.9973
0.6	.9977	.9976	.9975	.9975	.9974	.9973	.9973	.9972	.9971	.9970	.9969	.9968	.9967
0.7	.9973	.9972	.9971	.9971	.9970	.9969	.9968	.9967	.9966	.9965	.9964	.9963	.9962
0.8	.9969	.9968	.9967	.9967	.9966	.9965	.9964	.9963	.9962	.9961	.9960	.9959	.9957
0.9	.9966	.9965	.9964	.9963	.9962	.9961	.9960	.9959	.9957	.9956	.9955	.9953	.9952
1.0	.9962	.9961	.9960	.9959	.9958	.9957	.9955	.9954	.9953	.9951	.9950	.9948	.9947
1.1	.9958	.9957	.9956	.9955	.9953	.9952	.9951	.9949	.9948	.9946	.9945	.9943	.9941
1.2	.9954	.9953	.9952	.9951	.9949	.9948	.9946	.9945	.9943	.9941	.9940	.9938	.9936
1.3	.9951	.9949	.9948	.9946	.9945	.9943	.9942	.9940	.9938	.9936	.9934	.9933	.9931
1.4	.9947	.9945	.9944	.9942	.9941	.9939	.9938	.9936	.9934	.9932	.9930	.9928	.9926
1.5	.9944	.9942	.9941	.9939	.9937	.9935	.9933	.9932	.9929	.9927	.9925	.9923	.9920
1.6	.9940	.9938	.9937	.9935	.9933	.9931	.9929	.9927	.9925	.9922	.9920	.9918	.9915
1.7	.9936	.9934	.9933	.9931	.9929	.9927	.9925	.9923	.9921	.9918	.9916	.9913	.9910
1.8	.9932	.9930	.9928	.9927	.9925	.9923	.9920	.9918	.9916	.9913	.9911	.9908	.9905
1.9	.9929	.9927	.9925	.9923	.9921	.9919	.9916	.9914	.9911	.9908	.9906	.9903	.9900
2.0	.9923	.9921	.9919	.9917	.9915	.9912	.9910	.9907	.9904	.9901	.9898	.9896	.9892
2.1	.9921	.9919	.9917	.9915	.9913	.9910	.9908	.9905	.9902	.9899	.9896	.9893	.9890
2.2	.9918	.9916	.9913	.9911	.9908	.9906	.9903	.9900	.9897	.9894	.9892	.9888	.9884
2.3	.9915	.9913	.9910	.9908	.9905	.9902	.9900	.9897	.9894	.9891	.9887	.9884	.9880
2.4	.9911	.9909	.9906	.9904	.9901	.9898	.9896	.9892	.9889	.9886	.9882	.9879	.9875
2.5	.9907	.9905	.9902	.9900	.9897	.9894	.9891	.9888	.9885	.9881	.9878	.9874	.9870
2.6	.9904	.9902	.9899	.9896	.9893	.9890	.9887	.9884	.9880	.9876	.9873	.9869	.9865
2.7	.9900	.9898	.9895	.9892	.9889	.9886	.9883	.9880	.9876	.9872	.9869	.9864	.9860
2.8	.9897	.9895	.9892	.9889	.9886	.9882	.9879	.9875	.9871	.9867	.9864	.9859	.9855
2.9	.9893	.9891	.9888	.9885	.9882	.9878	.9874	.9871	.9867	.9863	.9859	.9855	.9850
3.0	.9890	.9887	.9884	.9881	.9877	.9874	.9870	.9867	.9863	.9859	.9854	.9850	.9845
3.1	.9887	.9884	.9881	.9877	.9874	.9870	.9867	.9863	.9859	.9854	.9850	.9845	.9840
3.2	.9883	.9880	.9877	.9873	.9870	.9866	.9862	.9858	.9854	.9850	.9845	.9840	.9835
3.3	.9880	.9877	.9873	.9870	.9866	.9863	.9859	.9854	.9850	.9845	.9841	.9836	.9831
3.4	.9876	.9873	.9869	.9866	.9862	.9858	.9854	.9850	.9845	.9841	.9836	.9831	.9825
3.5	.9873	.9870	.9866	.9863	.9859	.9855	.9850	.9846	.9841	.9837	.9832	.9826	.9821
3.6	.9869	.9866	.9862	.9859	.9855	.9851	.9846	.9842	.9837	.9833	.9827	.9822	.9816
3.7	.9866	.9863	.9859	.9855	.9851	.9847	.9842	.9838	.9833	.9828	.9822	.9817	.9811
3.8	.9863	.9859	.9855	.9851	.9847	.9843	.9838	.9834	.9829	.9824	.9818	.9813	.9807
3.9	.9860	.9856	.9852	.9848	.9844	.9839	.9835	.9830	.9825	.9820	.9814	.9808	.9802
4.0	.9857	.9853	.9849	.9845	.9840	.9836	.9831	.9826	.9820	.9815	.9809	.9803	.9797

Expansion Factors — Flange Taps Y_2

Static Pressure Taken from Downstream Taps

h_w/P_{f2} Ratio	$\beta = \frac{d}{D}$ Ratio												
	.1	.2	.3	.4	.45	.50	.52	.54	.56	.58	.60	.61	.62
0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.1	1.0007	1.0007	1.0007	1.0006	1.0006	1.0006	1.0006	1.0006	1.0006	1.0006	1.0005	1.0005	1.0005
0.2	1.0013	1.0013	1.0013	1.0013	1.0013	1.0012	1.0012	1.0012	1.0012	1.0011	1.0011	1.0011	1.0011
0.3	1.0020	1.0020	1.0020	1.0020	1.0019	1.0018	1.0018	1.0018	1.0017	1.0017	1.0016	1.0016	1.0016
0.4	1.0027	1.0027	1.0027	1.0026	1.0026	1.0025	1.0024	1.0024	1.0023	1.0023	1.0022	1.0022	1.0021
0.5	1.0033	1.0033	1.0033	1.0032	1.0031	1.0030	1.0029	1.0029	1.0028	1.0028	1.0027	1.0027	1.0027
0.6	1.0040	1.0040	1.0040	1.0039	1.0038	1.0036	1.0036	1.0035	1.0034	1.0033	1.0032	1.0032	1.0031
0.7	1.0047	1.0047	1.0047	1.0045	1.0044	1.0043	1.0042	1.0041	1.0040	1.0039	1.0038	1.0038	1.0037
0.8	1.0053	1.0053	1.0053	1.0051	1.0050	1.0049	1.0048	1.0047	1.0046	1.0045	1.0044	1.0043	1.0043
0.9	1.0060	1.0060	1.0060	1.0058	1.0057	1.0055	1.0054	1.0053	1.0052	1.0050	1.0049	1.0048	1.0048
1.0	1.0067	1.0066	1.0066	1.0064	1.0063	1.0061	1.0060	1.0059	1.0058	1.0056	1.0055	1.0054	1.0053
1.1	1.0074	1.0073	1.0073	1.0071	1.0069	1.0067	1.0066	1.0065	1.0063	1.0061	1.0060	1.0059	1.0058
1.2	1.0080	1.0080	1.0079	1.0077	1.0075	1.0073	1.0072	1.0071	1.0069	1.0067	1.0066	1.0065	1.0064
1.3	1.0087	1.0087	1.0086	1.0084	1.0082	1.0080	1.0078	1.0077	1.0075	1.0073	1.0071	1.0070	1.0069
1.4	1.0094	1.0093	1.0093	1.0090	1.0088	1.0086	1.0084	1.0083	1.0081	1.0079	1.0077	1.0076	1.0074
1.5	1.0100	1.0100	1.0099	1.0097	1.0094	1.0091	1.0090	1.0088	1.0086	1.0084	1.0082	1.0081	1.0080
1.6	1.0108	1.0107	1.0106	1.0104	1.0101	1.0097	1.0097	1.0095	1.0093	1.0090	1.0088	1.0086	1.0085
1.7	1.0114	1.0114	1.0113	1.0110	1.0108	1.0104	1.0103	1.0101	1.0099	1.0096	1.0094	1.0092	1.0091
1.8	1.0121	1.0120	1.0120	1.0117	1.0114	1.0110	1.0108	1.0106	1.0104	1.0102	1.0100	1.0097	1.0096
1.9	1.0128	1.0127	1.0126	1.0123	1.0120	1.0116	1.0115	1.0112	1.0110	1.0107	1.0104	1.0103	1.0101
2.0	1.0134	1.0133	1.0132	1.0129	1.0126	1.0122	1.0121	1.0118	1.0116	1.0113	1.0110	1.0108	1.0106
2.1	1.0140	1.0140	1.0139	1.0136	1.0133	1.0129	1.0127	1.0124	1.0122	1.0119	1.0115	1.0114	1.0111
2.2	1.0147	1.0147	1.0146	1.0142	1.0139	1.0135	1.0133	1.0130	1.0128	1.0125	1.0121	1.0120	1.0118
2.3	1.0154	1.0154	1.0153	1.0149	1.0146	1.0141	1.0139	1.0136	1.0133	1.0130	1.0127	1.0125	1.0123
2.4	1.0160	1.0160	1.0159	1.0154	1.0151	1.0146	1.0144	1.0141	1.0138	1.0135	1.0133	1.0130	1.0128
2.5	1.0167	1.0167	1.0166	1.0162	1.0158	1.0153	1.0150	1.0148	1.0145	1.0141	1.0137	1.0135	1.0133
2.6	1.0174	1.0173	1.0172	1.0168	1.0164	1.0159	1.0156	1.0154	1.0151	1.0147	1.0143	1.0141	1.0139
2.7	1.0183	1.0182	1.0181	1.0176	1.0172	1.0167	1.0164	1.0161	1.0158	1.0154	1.0150	1.0148	1.0146
2.8	1.0187	1.0186	1.0185	1.0180	1.0176	1.0171	1.0168	1.0165	1.0162	1.0158	1.0154	1.0152	1.0149
2.9	1.0194	1.0194	1.0192	1.0187	1.0183	1.0177	1.0175	1.0172	1.0168	1.0164	1.0160	1.0157	1.0155
3.0	1.0200	1.0200	1.0198	1.0193	1.0189	1.0183	1.0180	1.0177	1.0173	1.0169	1.0165	1.0162	1.0160
3.1	1.0207	1.0206	1.0205	1.0200	1.0195	1.0189	1.0186	1.0183	1.0179	1.0175	1.0171	1.0168	1.0166
3.2	1.0213	1.0213	1.0211	1.0206	1.0201	1.0195	1.0192	1.0189	1.0185	1.0180	1.0176	1.0173	1.0171
3.3	1.0220	1.0220	1.0218	1.0213	1.0208	1.0202	1.0199	1.0195	1.0191	1.0186	1.0181	1.0178	1.0176
3.4	1.0227	1.0227	1.0225	1.0219	1.0214	1.0208	1.0205	1.0201	1.0197	1.0192	1.0187	1.0184	1.0182
3.5	1.0233	1.0233	1.0231	1.0225	1.0220	1.0214	1.0210	1.0207	1.0202	1.0198	1.0192	1.0190	1.0187
3.6	1.0240	1.0239	1.0237	1.0232	1.0227	1.0220	1.0216	1.0212	1.0208	1.0203	1.0198	1.0195	1.0192
3.7	1.0246	1.0246	1.0244	1.0238	1.0232	1.0225	1.0221	1.0217	1.0213	1.0208	1.0203	1.0200	1.0197
3.8	1.0252	1.0252	1.0250	1.0244	1.0238	1.0231	1.0227	1.0223	1.0219	1.0214	1.0209	1.0206	1.0203
3.9	1.0259	1.0259	1.0257	1.0250	1.0245	1.0237	1.0234	1.0229	1.0225	1.0220	1.0214	1.0211	1.0208
4.0	1.0265	1.0265	1.0263	1.0256	1.0251	1.0243	1.0240	1.0235	1.0231	1.0225	1.0220	1.0217	1.0213

h_w/P_{f2} Ratio	$\beta = \frac{d}{D}$ Ratio												
	.63	.64	.65	.66	.67	.68	.69	.70	.71	.72	.73	.74	.75
0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.1	1.0005	1.0005	1.0005	1.0005	1.0005	1.0005	1.0004	1.0004	1.0004	1.0004	1.0004	1.0004	1.0004
0.2	1.0010	1.0010	1.0010	1.0010	1.0010	1.0009	1.0009	1.0009	1.0008	1.0008	1.0008	1.0008	1.0007
0.3	1.0016	1.0015	1.0015	1.0015	1.0014	1.0014	1.0014	1.0013	1.0013	1.0012	1.0012	1.0011	1.0011
0.4	1.0021	1.0021	1.0020	1.0020	1.0019	1.0019	1.0018	1.0018	1.0017	1.0017	1.0016	1.0015	1.0015
0.5	1.0026	1.0026	1.0025	1.0025	1.0024	1.0024	1.0023	1.0022	1.0022	1.0021	1.0020	1.0019	1.0019
0.6	1.0031	1.0030	1.0030	1.0029	1.0028	1.0027	1.0027	1.0026	1.0025	1.0024	1.0023	1.0022	1.0022
0.7	1.0036	1.0036	1.0035	1.0034	1.0033	1.0032	1.0031	1.0031	1.0030	1.0029	1.0028	1.0026	1.0025
0.8	1.0042	1.0041	1.0040	1.0039	1.0038	1.0037	1.0036	1.0035	1.0034	1.0033	1.0032	1.0031	1.0029
0.9	1.0047	1.0046	1.0045	1.0043	1.0042	1.0041	1.0040	1.0039	1.0039	1.0037	1.0036	1.0035	1.0033
1.0	1.0052	1.0051	1.0050	1.0049	1.0048	1.0046	1.0045	1.0044	1.0043	1.0041	1.0040	1.0039	1.0037
1.1	1.0057	1.0056	1.0055	1.0054	1.0053	1.0051	1.0050	1.0049	1.0047	1.0046	1.0044	1.0042	1.0040
1.2	1.0062	1.0061	1.0060	1.0059	1.0057	1.0056	1.0054	1.0053	1.0051	1.0050	1.0048	1.0046	1.0044
1.3	1.0067	1.0066	1.0065	1.0064	1.0062	1.0061	1.0059	1.0058	1.0056	1.0054	1.0052	1.0050	1.0048
1.4	1.0073	1.0072	1.0070	1.0069	1.0067	1.0065	1.0063	1.0062	1.0060	1.0058	1.0056	1.0054	1.0052
1.5	1.0078	1.0077	1.0075	1.0074	1.0072	1.0070	1.0068	1.0067	1.0065	1.0063	1.0060	1.0058	1.0056
1.6	1.0083	1.0081	1.0080	1.0078	1.0076	1.0075	1.0073	1.0071	1.0069	1.0066	1.0064	1.0062	1.0059
1.7	1.0089	1.0087	1.0086	1.0084	1.0082	1.0080	1.0078	1.0076	1.0074	1.0071	1.0069	1.0066	1.0064
1.8	1.0094	1.0092	1.0091	1.0089	1.0087	1.0084	1.0082	1.0080	1.0078	1.0075	1.0073	1.0070	1.0067
1.9	1.0099	1.0097	1.0095	1.0093	1.0091	1.0089	1.0087	1.0084	1.0082	1.0079	1.0077	1.0074	1.0071
2.0	1.0104	1.0102	1.0100	1.0098	1.0096	1.0094	1.0092	1.0089	1.0087	1.0084	1.0081	1.0078	1.0075
2.1	1.0110	1.0108	1.0105	1.0103	1.0101	1.0099	1.0096	1.0094	1.0091	1.0088	1.0085	1.0082	1.0079
2.2	1.0116	1.0114	1.0111	1.0109	1.0107	1.0104	1.0101	1.0098	1.0095	1.0094	1.0089	1.0086	1.0083
2.3	1.0121	1.0119	1.0116	1.0114	1.0111	1.0109	1.0106	1.0103	1.0100	1.0097	1.0093	1.0090	1.0086
2.4	1.0126	1.0124	1.0121	1.0119	1.0116	1.0114	1.0111	1.0108	1.0105	1.0102	1.0098	1.0095	1.0091
2.5	1.0131	1.0128	1.0126	1.0123	1.0120	1.0118	1.0115	1.0112	1.0109	1.0106	1.0102	1.0098	1.0094
2.6	1.0136	1.0134	1.0131	1.0128	1.0125	1.0123	1.0120	1.0116	1.0113	1.0110	1.0106	1.0102	1.0099
2.7	1.0143	1.0141	1.0138	1.0135	1.0132	1.0129	1.0126	1.0123	1.0119	1.0115	1.0111	1.0107	1.0103
2.8	1.0147	1.0144	1.0141	1.0139	1.0136	1.0132	1.0129	1.0126	1.0122	1.0118	1.0114	1.0110	1.0106
2.9	1.0152	1.0150	1.0147	1.0144	1.0141	1.0137	1.0134	1.0130	1.0127	1.0123	1.0119	1.0114	1.0110
3.0	1.0157	1.0156	1.0152	1.0149	1.0146	1.0142	1.0139	1.0135	1.0131	1.0127	1.0123	1.0119	1.0114
3.1	1.0163	1.0160	1.0157	1.0153	1.0150	1.0147	1.0143	1.0139	1.0135	1.0131	1.0127	1.0123	1.0118
3.2	1.0168	1.0165	1.0162	1.0158	1.0155	1.0152	1.0148	1.0144	1.0140	1.0136	1.0131	1.0127	1.0122
3.3	1.0173	1.0170	1.0166	1.0163	1.0159	1.0156	1.0152	1.0148	1.0144	1.0139	1.0135	1.0130	1.0125
3.4	1.0179	1.0175	1.0172	1.0169	1.0165	1.0161	1.0157	1.0153	1.0149	1.0144	1.0139	1.0135	1.0129
3.5	1.0183	1.0180	1.0177	1.0173	1.0169	1.0166	1.0161	1.0157	1.0153	1.0148	1.0143	1.0139	1.0133
3.6	1.0188	1.0185	1.0182	1.0178	1.0174	1.0170	1.0166	1.0162	1.0158	1.0153	1.0148	1.0143	1.0138
3.7	1.0193	1.0190	1.0187	1.0183	1.0179	1.0175	1.0171	1.0166	1.0162	1.0157	1.0152	1.0146	1.0141
3.8	1.0199	1.0195	1.0192	1.0188	1.0185	1.0180	1.0176	1.0171	1.0167	1.0162	1.0156	1.0151	1.0145
3.9	1.0205	1.0201	1.0197	1.0193	1.0189	1.0185	1.0180	1.0176	1.0171	1.0166	1.0160	1.0155	1.0149
4.0	1.0210	1.0206	1.0202	1.0198	1.0194	1.0190	1.0185	1.0180	1.0175	1.0170	1.0164	1.0159	1.0153

TABLE 7-A

Expansion Factors, Y_1 — Pipe Taps

Static Pressure Taken from Upstream Taps

$\frac{h_w}{p_{f1}}$ Ratio	$\beta = \frac{d}{D}$ Ratio									
	.61	.62	.63	.64	.65	.66	.67	.68	.69	.70
0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.1	.9976	.9976	.9975	.9974	.9973	.9972	.9971	.9970	.9969	.9968
0.2	.9953	.9951	.9950	.9948	.9947	.9945	.9943	.9941	.9938	.9935
0.3	.9929	.9927	.9925	.9923	.9920	.9917	.9914	.9911	.9907	.9903
0.4	.9906	.9903	.9900	.9897	.9893	.9890	.9886	.9881	.9876	.9871
0.5	.9882	.9879	.9875	.9871	.9867	.9862	.9857	.9851	.9845	.9839
0.6	.9859	.9854	.9850	.9845	.9840	.9834	.9828	.9822	.9814	.9806
0.7	.9835	.9830	.9825	.9819	.9813	.9807	.9800	.9792	.9784	.9774
0.8	.9811	.9806	.9800	.9794	.9787	.9779	.9771	.9762	.9753	.9742
0.9	.9788	.9782	.9775	.9768	.9760	.9752	.9742	.9733	.9722	.9710
1.0	.9764	.9757	.9750	.9742	.9733	.9724	.9714	.9703	.9691	.9677
1.1	.9741	.9733	.9725	.9716	.9707	.9696	.9685	.9673	.9660	.9645
1.2	.9717	.9709	.9700	.9690	.9680	.9669	.9657	.9643	.9629	.9613
1.3	.9694	.9685	.9675	.9664	.9653	.9641	.9628	.9614	.9598	.9581
1.4	.9670	.9660	.9650	.9639	.9627	.9614	.9599	.9584	.9567	.9548
1.5	.9646	.9636	.9625	.9613	.9600	.9585	.9571	.9554	.9536	.9516
1.6	.9623	.9612	.9600	.9587	.9573	.9558	.9542	.9525	.9505	.9484
1.7	.9599	.9587	.9575	.9561	.9547	.9531	.9514	.9496	.9474	.9452
1.8	.9576	.9563	.9550	.9535	.9520	.9503	.9485	.9465	.9443	.9419
1.9	.9552	.9539	.9525	.9510	.9493	.9476	.9456	.9435	.9412	.9387
2.0	.9529	.9515	.9500	.9484	.9467	.9448	.9428	.9406	.9381	.9355
2.1	.9505	.9490	.9475	.9458	.9440	.9420	.9399	.9376	.9351	.9323
2.2	.9481	.9466	.9450	.9432	.9413	.9393	.9371	.9346	.9320	.9290
2.3	.9458	.9442	.9425	.9406	.9387	.9365	.9342	.9317	.9289	.9258
2.4	.9434	.9418	.9400	.9381	.9360	.9338	.9313	.9287	.9258	.9226
2.5	.9411	.9393	.9375	.9355	.9333	.9310	.9285	.9257	.9227	.9194
2.6	.9387	.9369	.9350	.9329	.9307	.9282	.9256	.9227	.9196	.9161
2.7	.9364	.9345	.9325	.9303	.9280	.9255	.9227	.9198	.9165	.9129
2.8	.9340	.9321	.9300	.9277	.9253	.9227	.9199	.9168	.9134	.9097
2.9	.9316	.9296	.9275	.9252	.9227	.9200	.9170	.9138	.9103	.9064
3.0	.9293	.9272	.9250	.9226	.9200	.9172	.9142	.9108	.9072	.9032
3.1	.9269	.9248	.9225	.9200	.9173	.9144	.9113	.9079	.9041	.9000
3.2	.9246	.9223	.9200	.9174	.9147	.9117	.9084	.9049	.9010	.8968
3.3	.9222	.9199	.9175	.9148	.9120	.9089	.9056	.9019	.8979	.8935
3.4	.9199	.9175	.9150	.9122	.9093	.9062	.9027	.8990	.8948	.8903
3.5	.9175	.9151	.9125	.9097	.9067	.9034	.8999	.8960	.8918	.8871
3.6	.9151	.9126	.9100	.9071	.9040	.9006	.8970	.8930	.8887	.8839
3.7	.9128	.9102	.9075	.9045	.9013	.8979	.8941	.8900	.8856	.8806
3.8	.9104	.9078	.9050	.9019	.8987	.8951	.8913	.8871	.8825	.8774
3.9	.9081	.9054	.9025	.8993	.8960	.8924	.8884	.8841	.8794	.8742
4.0	.9057	.9029	.9000	.8968	.8933	.8896	.8856	.8811	.8763	.8710

$\frac{h_w}{p_{f1}}$ Ratio	$\beta = \frac{d}{D}$ Ratio											
	.1	.2	.3	.4	.45	.50	.52	.54	.56	.58	.60
0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.1	.9990	.9989	.9988	.9985	.9984	.9982	.9981	.9980	.9979	.9978	.9977
0.2	.9981	.9979	.9976	.9971	.9968	.9964	.9962	.9961	.9959	.9957	.9954
0.3	.9971	.9968	.9964	.9956	.9952	.9946	.9944	.9941	.9938	.9935	.9931
0.4	.9962	.9958	.9951	.9942	.9936	.9928	.9925	.9921	.9917	.9913	.9908
0.5	.9952	.9947	.9939	.9927	.9919	.9910	.9906	.9902	.9897	.9891	.9885
0.6	.9943	.9937	.9927	.9913	.9903	.9892	.9887	.9882	.9876	.9870	.9862
0.7	.9933	.9928	.9915	.9898	.9887	.9874	.9869	.9862	.9856	.9848	.9840
0.8	.9923	.9916	.9903	.9883	.9871	.9857	.9850	.9843	.9835	.9826	.9817
0.9	.9914	.9905	.9891	.9869	.9855	.9839	.9831	.9823	.9814	.9805	.9794
1.0	.9904	.9895	.9878	.9854	.9839	.9821	.9812	.9803	.9794	.9783	.9771
1.1	.9895	.9884	.9866	.9840	.9823	.9803	.9794	.9784	.9773	.9761	.9748
1.2	.9885	.9874	.9854	.9825	.9807	.9785	.9775	.9764	.9752	.9739	.9725
1.3	.9876	.9863	.9842	.9811	.9791	.9767	.9756	.9744	.9732	.9718	.9702
1.4	.9866	.9853	.9830	.9796	.9775	.9749	.9737	.9725	.9711	.9696	.9679
1.5	.9857	.9842	.9818	.9782	.9758	.9731	.9719	.9705	.9690	.9674	.9656
1.6	.9847	.9832	.9805	.9767	.9742	.9713	.9700	.9685	.9670	.9652	.9633
1.7	.9837	.9821	.9793	.9752	.9726	.9695	.9681	.9666	.9649	.9631	.9610
1.8	.9828	.9811	.9781	.9738	.9710	.9677	.9662	.9646	.9628	.9609	.9587
1.9	.9818	.9800	.9769	.9723	.9694	.9659	.9643	.9626	.9608	.9587	.9565
2.0	.9809	.9790	.9757	.9709	.9678	.9641	.9625	.9607	.9587	.9566	.9542
2.1	.9799	.9779	.9745	.9694	.9662	.9623	.9606	.9587	.9566	.9544	.9519
2.2	.9790	.9768	.9732	.9680	.9646	.9605	.9587	.9567	.9546	.9522	.9496
2.3	.9780	.9758	.9720	.9665	.9630	.9587	.9568	.9548	.9525	.9500	.9473
2.4	.9770	.9747	.9708	.9650	.9613	.9570	.9550	.9528	.9505	.9479	.9450
2.5	.9761	.9737	.9696	.9636	.9597	.9552	.9531	.9508	.9484	.9457	.9427
2.6	.9751	.9726	.9684	.9621	.9581	.9534	.9512	.9489	.9463	.9435	.9404
2.7	.9742	.9716	.9672	.9607	.9565	.9516	.9493	.9469	.9443	.9414	.9381
2.8	.9732	.9705	.9659	.9592	.9549	.9498	.9475	.9449	.9422	.9392	.9358
2.9	.9723	.9695	.9647	.9578	.9533	.9480	.9456	.9430	.9401	.9370	.9335
3.0	.9713	.9684	.9635	.9563	.9517	.9462	.9437	.9410	.9381	.9348	.9312
3.1	.9704	.9674	.9623	.9549	.9501	.9444	.9418	.9390	.9360	.9327	.9290
3.2	.9694	.9663	.9611	.9534	.9485	.9426	.9400	.9371	.9339	.9305	.9267
3.3	.9684	.9653	.9599	.9519	.9469	.9408	.9381	.9351	.9319	.9283	.9244
3.4	.9675	.9642	.9587	.9505	.9452	.9390	.9362	.9331	.9298	.9261	.9221
3.5	.9665	.9632	.9574	.9490	.9436	.9372	.9343	.9312	.9277	.9240	.9198
3.6	.9656	.9621	.9562	.9476	.9420	.9354	.9324	.9292	.9257	.9218	.9175
3.7	.9646	.9611	.9550	.9461	.9404	.9336	.9306	.9272	.9236	.9196	.9152
3.8	.9637	.9600	.9538	.9447	.9388	.9318	.9287	.9253	.9216	.9175	.9129
3.9	.9627	.9590	.9526	.9432	.9372	.9301	.9268	.9233	.9195	.9153	.9106
4.0	.9617	.9579	.9514	.9417	.9356	.9283	.9249	.9213	.9174	.9131	.9083

Expansion Factors, Y_2 — Pipe Taps

Static Pressure Taken from Downstream Taps

$\frac{h_w}{p_{f2}}$ Ratio	$\beta = \frac{d}{D}$ Ratio										
	.1	.2	.3	.4	.45	.50	.52	.54	.56	.58	.60
0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.1	1.0008	1.0007	1.0006	1.0003	1.0002	1.0000	.9999	.9998	.9997	.9996	.9995
0.2	1.0017	1.0015	1.0012	1.0007	1.0004	1.0000	.9998	.9997	.9995	.9993	.9990
0.3	1.0025	1.0023	1.0018	1.0010	1.0006	1.0000	.9998	.9995	.9992	.9989	.9985
0.4	1.0033	1.0031	1.0024	1.0014	1.0008	1.0000	.9997	.9994	.9989	.9985	.9980
0.5	1.0042	1.0037	1.0029	1.0018	1.0010	1.0001	.9997	.9993	.9987	.9982	.9975
0.6	1.0051	1.0045	1.0035	1.0021	1.0012	1.0001	.9996	.9991	.9985	.9979	.9972
0.7	1.0059	1.0053	1.0042	1.0024	1.0014	1.0001	.9996	.9989	.9983	.9976	.9968
0.8	1.0068	1.0060	1.0048	1.0028	1.0016	1.0002	.9995	.9988	.9981	.9972	.9963
0.9	1.0076	1.0068	1.0053	1.0032	1.0018	1.0003	.9995	.9987	.9978	.9969	.9958
1.0	1.0084	1.0075	1.0059	1.0036	1.0021	1.0003	.9994	.9986	.9976	.9965	.9954
1.1	1.0093	1.0082	1.0065	1.0039	1.0023	1.0004	.9994	.9984	.9974	.9962	.9949
1.2	1.0101	1.0090	1.0071	1.0043	1.0025	1.0004	.9994	.9984	.9972	.9959	.9945
1.3	1.0110	1.0098	1.0077	1.0047	1.0027	1.0004	.9994	.9982	.9969	.9956	.9941
1.4	1.0119	1.0106	1.0083	1.0050	1.0030	1.0005	.9993	.9981	.9967	.9953	.9937
1.5	1.0127	1.0113	1.0089	1.0054	1.0032	1.0005	.9993	.9980	.9965	.9950	.9932
1.6	1.0136	1.0121	1.0095	1.0058	1.0034	1.0006	.9993	.9979	.9964	.9947	.9928
1.7	1.0143	1.0128	1.0101	1.0062	1.0036	1.0006	.9993	.9978	.9962	.9944	.9924
1.8	1.0152	1.0136	1.0107	1.0065	1.0038	1.0007	.9992	.9977	.9960	.9942	.9920
1.9	1.0161	1.0143	1.0113	1.0069	1.0041	1.0008	.9992	.9976	.9958	.9938	.9916
2.0	1.0169	1.0150	1.0119	1.0073	1.0044	1.0008	.9992	.9975	.9956	.9935	.9912
2.1	1.0177	1.0158	1.0125	1.0077	1.0046	1.0008	.9992	.9974	.9954	.9933	.9908
2.2	1.0185	1.0165	1.0131	1.0081	1.0048	1.0009	.9992	.9973	.9953	.9930	.9905
2.3	1.0194	1.0173	1.0137	1.0084	1.0050	1.0010	.9992	.9972	.9951	.9928	.9902
2.4	1.0202	1.0180	1.0142	1.0089	1.0053	1.0011	.9992	.9971	.9949	.9924	.9897
2.5	1.0210	1.0188	1.0148	1.0092	1.0056	1.0012	.9992	.9971	.9948	.9922	.9894
2.6	1.0219	1.0195	1.0154	1.0096	1.0058	1.0013	.9992	.9970	.9946	.9919	.9890
2.7	1.0230	1.0205	1.0162	1.0101	1.0061	1.0014	.9992	.9969	.9944	.9916	.9885
2.8	1.0236	1.0210	1.0166	1.0104	1.0063	1.0014	.9992	.9969	.9943	.9914	.9882
2.9	1.0244	1.0217	1.0173	1.0107	1.0065	1.0015	.9992	.9968	.9941	.9912	.9879
3.0	1.0251	1.0224	1.0179	1.0111	1.0067	1.0017	.9992	.9967	.9939	.9910	.9875
3.1	1.0259	1.0232	1.0185	1.0115	1.0070	1.0018	.9993	.9966	.9938	.9907	.9872
3.2	1.0267	1.0239	1.0190	1.0119	1.0072	1.0018	.9993	.9966	.9936	.9905	.9869
3.3	1.0276	1.0247	1.0196	1.0122	1.0075	1.0019	.9993	.9966	.9935	.9903	.9866
3.4	1.0284	1.0253	1.0202	1.0126	1.0077	1.0020	.9994	.9965	.9934	.9901	.9863
3.5	1.0291	1.0261	1.0208	1.0130	1.0080	1.0021	.9994	.9964	.9933	.9898	.9860
3.6	1.0301	1.0268	1.0214	1.0134	1.0083	1.0022	.9994	.9964	.9931	.9896	.9857
3.7	1.0309	1.0276	1.0219	1.0137	1.0085	1.0023	.9995	.9964	.9930	.9894	.9854
3.8	1.0316	1.0287	1.0225	1.0141	1.0088	1.0024	.9995	.9963	.9929	.9892	.9850
3.9	1.0324	1.0290	1.0231	1.0145	1.0091	1.0025	.9995	.9963	.9928	.9889	.9847
4.0	1.0332	1.0297	1.0237	1.0149	1.0093	1.0025	.9995	.9963	.9927	.9887	.9844

$\frac{h_w}{p_{f2}}$ Ratio	$\beta = \frac{d}{D}$ Ratio									
	.61	.62	.63	.64	.65	.66	.67	.68	.69	.70
0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.1	.9994	.9994	.9993	.9992	.9991	.9990	.9989	.9988	.9987	.9986
0.2	.9989	.9987	.9986	.9984	.9983	.9981	.9979	.9977	.9974	.9971
0.3	.9983	.9981	.9979	.9977	.9974	.9971	.9968	.9965	.9962	.9958
0.4	.9978	.9975	.9972	.9969	.9966	.9963	.9959	.9954	.9949	.9944
0.5	.9973	.9970	.9966	.9962	.9958	.9953	.9948	.9942	.9936	.9930
0.6	.9969	.9964	.9959	.9954	.9949	.9943	.9937	.9931	.9924	.9916
0.7	.9963	.9958	.9953	.9947	.9940	.9932	.9928	.9920	.9912	.9903
0.8	.9957	.9952	.9947	.9941	.9933	.9925	.9918	.9909	.9900	.9889
0.9	.9952	.9947	.9940	.9933	.9925	.9917	.9907	.9898	.9888	.9876
1.0	.9947	.9941	.9934	.9926	.9917	.9908	.9898	.9887	.9876	.9863
1.1	.9942	.9935	.9927	.9919	.9910	.9899	.9889	.9877	.9865	.9849
1.2	.9938	.9929	.9921	.9911	.9902	.9890	.9878	.9865	.9851	.9835
1.3	.9933	.9924	.9914	.9904	.9893	.9881	.9869	.9855	.9839	.9823
1.4	.9928	.9918	.9908	.9897	.9886	.9873	.9859	.9845	.9827	.9810
1.5	.9923	.9913	.9903	.9891	.9878	.9865	.9849	.9834	.9815	.9796
1.6	.9919	.9908	.9897	.9883	.9870	.9856	.9840	.9823	.9804	.9784
1.7	.9914	.9902	.9890	.9876	.9863	.9848	.9831	.9813	.9793	.9771
1.8	.9909	.9897	.9884	.9870	.9855	.9840	.9822	.9802	.9781	.9758
1.9	.9905	.9892	.9878	.9863	.9848	.9831	.9812	.9792	.9770	.9746
2.0	.9900	.9887	.9872	.9857	.9840	.9823	.9803	.9782	.9759	.9733
2.1	.9895	.9882	.9867	.9851	.9833	.9815	.9794	.9771	.9748	.9720
2.2	.9891	.9876	.9861	.9844	.9826	.9807	.9785	.9762	.9737	.9708
2.3	.9887	.9871	.9855	.9837	.9818	.9798	.9776	.9752	.9726	.9696
2.4	.9882	.9866	.9850	.9831	.9812	.9791	.9768	.9742	.9715	.9683
2.5	.9878	.9861	.9844	.9825	.9805	.9783	.9759	.9732	.9704	.9672
2.6	.9874	.9857	.9839	.9819	.9798	.9775	.9750	.9722	.9693	.9660
2.7	.9869	.9850	.9832	.9811	.9788	.9765	.9738	.9709	.9679	.9644
2.8	.9866	.9847	.9828	.9807	.9784	.9759	.9732	.9703	.9672	.9636
2.9	.9861	.9842	.9822	.9800	.9777	.9751	.9723	.9693	.9660	.9624
3.0	.9857	.9838	.9817	.9794	.9770	.9744	.9715	.9685	.9650	.9613
3.1	.9853	.9834	.9812	.9788	.9763	.9737	.9707	.9676	.9640	.9602
3.2	.9849	.9829	.9807	.9783	.9757	.9729	.9699	.9666	.9630	.9590
3.3	.9846	.9825	.9802	.9777	.9750	.9722	.9690	.9657	.9619	.9579
3.4	.9842	.9820	.9797	.9771	.9744	.9715	.9683	.9648	.9609	.9568
3.5	.9838	.9816	.9792	.9765	.9738	.9707	.9675	.9639	.9600	.9556
3.6	.9834	.9811	.9787	.9760	.9731	.9700	.9666	.9630	.9590	.9545
3.7	.9831	.9807	.9782	.9755	.9725	.9693	.9658	.9621	.9579	.9534
3.8	.9827	.9802	.9777	.9749	.9719	.9686	.9651	.9613	.9570	.9523
3.9	.9823	.9798	.9773	.9743	.9712	.9679	.9643	.9604	.9560	.9512
4.0	.9820	.9795	.9769	.9738	.9706	.9673	.9636	.9595	.9551	.9502

TABLE 8

Pressure Base Factors — F_{pb}

$F_{pb} = 14.4 \div$ base pressure, psia

CONTRACT PRESSURE BASE				CONTRACT PRESSURE BASE			
Above 14.4		Absolute Lb	F_{pb} Correction Factors	Above 14.4		Absolute Lb	F_{pb} Correction Factors
Oz.	Lb			Oz.	Lb		
2	.125	14.525	.9914	30	1.875	16.275	.8848
4	.250	14.65	.9829	32	2.000	16.40	.8780
(30" Hg., Absolute)		14.73	.9776	34	2.125	16.525	.8714
6	.375	14.775	.9746	36	2.250	16.65	.8649
8	.500	14.90	.9664	38	2.375	16.775	.8584
10	.625	15.025	.9584	40	2.500	16.90	.8521
12	.750	15.15	.9505	42	2.625	17.025	.8458
14	.875	15.275	.9427	44	2.750	17.15	.8397
16	1.000	15.40	.9351	46	2.875	17.275	.8336
18	1.125	15.525	.9275	48	3.000	17.40	.8276
20	1.250	15.65	.9201				
22	1.375	15.775	.9128				
24	1.500	15.90	.9057				
26	1.625	16.025	.8986				
28	1.750	16.15	.8916				

TABLE 9

Temperature Base Factors — F_{tb}

$$F_{tb} = \frac{460 + \text{Temperature base °F}}{520}$$

Temp. °F	F_{tb}	Temp. °F	F_{tb}	Temp. °F	F_{tb}	Temp. °F	F_{tb}
40	.9615	55	.9904	70	1.0192	85	1.0481
41	.9635	56	.9923	71	1.0212	86	1.0500
42	.9654	57	.9942	72	1.0231	87	1.0519
43	.9673	58	.9962	73	1.0250	88	1.0538
44	.9692	59	.9981	74	1.0269	89	1.0558
45	.9712	60	1.0000	75	1.0288	90	1.0577
46	.9731	61	1.0019	76	1.0308	95	1.0673
47	.9750	62	1.0038	77	1.0327	100	1.0769
48	.9769	63	1.0058	78	1.0346		
49	.9788	64	1.0077	79	1.0365		
50	.9808	65	1.0096	80	1.0385		
51	.9827	66	1.0115	81	1.0404		
52	.9846	67	1.0135	82	1.0425		
53	.9865	68	1.0154	83	1.0442		
54	.9885	69	1.0173	84	1.0462		

TABLE 10

Flowing Temperature Factors — F_{tf}

$$F_{tf} = \sqrt{\frac{520}{460 + \text{actual flowing temperature}}}$$

Temp. °F	F_{tf}	Temp. °F	F_{tf}	Temp. °F	F_{ft}	Temp. °F	F_{tf}
1	1.0621	41	1.0188	81	.9804	121	.9460
2	1.0609	42	1.0178	82	.9795	122	.9452
3	1.0598	43	1.0168	83	.9786	123	.9444
4	1.0586	44	1.0158	84	.9777	124	.9436
5	1.0575	45	1.0147	85	.9768	125	.9428
6	1.0564	46	1.0137	86	.9759	126	.9420
7	1.0552	47	1.0127	87	.9750	127	.9412
8	1.0541	48	1.0117	88	.9741	128	.9404
9	1.0530	49	1.0108	89	.9732	129	.9396
10	1.0518	50	1.0098	90	.9723	130	.9388
11	1.0507	51	1.0088	91	.9715	131	.9380
12	1.0496	52	1.0078	92	.9706	132	.9372
13	1.0485	53	1.0068	93	.9697	133	.9364
14	1.0474	54	1.0058	94	.9688	134	.9356
15	1.0463	55	1.0048	95	.9680	135	.9349
16	1.0452	56	1.0039	96	.9671	136	.9341
17	1.0441	57	1.0029	97	.9662	137	.9333
18	1.0430	58	1.0019	98	.9653	138	.9325
19	1.0419	59	1.0010	99	.9645	139	.9317
20	1.0408	60	1.0000	100	.9636	140	.9309
21	1.0398	61	.9990	101	.9628	141	.9302
22	1.0387	62	.9981	102	.9619	142	.9294
23	1.0376	63	.9971	103	.9610	143	.9286
24	1.0365	64	.9962	104	.9602	144	.9279
25	1.0355	65	.9952	105	.9594	145	.9271
26	1.0344	66	.9943	106	.9585	146	.9263
27	1.0333	67	.9933	107	.9577	147	.9256
28	1.0323	68	.9924	108	.9568	148	.9248
29	1.0312	69	.9915	109	.9560	149	.9240
30	1.0302	70	.9905	110	.9551	150	.9233
31	1.0291	71	.9896	111	.9543		
32	1.0281	72	.9887	112	.9535		
33	1.0270	73	.9877	113	.9526		
34	1.0260	74	.9868	114	.9518		
35	1.0249	75	.9859	115	.9510		
36	1.0239	76	.9850	116	.9501		
37	1.0229	77	.9840	117	.9493		
38	1.0218	78	.9831	118	.9485		
39	1.0208	79	.9822	119	.9477		
40	1.0198	80	.9813	120	.9469		

TABLE 11

Specific Gravity Factors — F_g

$$F_g = \sqrt{\frac{1.0000}{G}}$$

Specific gravity G	Factor F_g	Specific gravity G	Factor F_g	Specific gravity G	Factor F_g	Specific gravity G	Factor F_g
0.500	1.4142	0.675	1.2172	0.850	1.0847	1.05	0.9759
0.505	1.4072	0.680	1.2127	0.855	1.0815	1.06	0.9713
0.510	1.4003	0.685	1.2082	0.860	1.0783	1.07	0.9667
0.515	1.3935	0.690	1.2039	0.865	1.0752	1.08	0.9623
0.520	1.3868	0.695	1.1995	0.870	1.0721	1.09	0.9578
0.525	1.3801	0.700	1.1952	0.875	1.0690	1.10	0.9535
0.530	1.3736	0.705	1.1910	0.880	1.0660	1.11	0.9492
0.535	1.3672	0.710	1.1868	0.885	1.0630	1.12	0.9449
0.540	1.3608	0.715	1.1826	0.890	1.0600	1.13	0.9407
0.545	1.3546	0.720	1.1785	0.895	1.0570	1.14	0.9366
0.550	1.3484	0.725	1.1744	0.900	1.0541	1.15	0.9325
0.555	1.3423	0.730	1.1704	0.905	1.0512	1.16	0.9285
0.560	1.3363	0.735	1.1664	0.910	1.0483	1.17	0.9245
0.565	1.3304	0.740	1.1625	0.915	1.0454	1.18	0.9206
0.570	1.3245	0.745	1.1586	0.920	1.0426	1.19	0.9167
0.575	1.3188	0.750	1.1547	0.925	1.0398	1.20	0.9129
0.580	1.3131	0.755	1.1509	0.930	1.0370	1.21	0.9091
0.585	1.3074	0.760	1.1471	0.935	1.0342	1.22	0.9054
0.590	1.3019	0.765	1.1433	0.940	1.0314	1.23	0.9017
0.595	1.2964	0.770	1.1396	0.945	1.0287	1.24	0.8980
0.600	1.2910	0.775	1.1359	0.950	1.0260	1.25	0.8944
0.605	1.2856	0.780	1.1323	0.955	1.0233	1.26	0.8909
0.610	1.2804	0.785	1.1287	0.960	1.0206	1.27	0.8874
0.615	1.2752	0.790	1.1251	0.965	1.0180	1.28	0.8839
0.620	1.2700	0.795	1.1215	0.970	1.0153	1.29	0.8805
0.625	1.2649	0.800	1.1180	0.975	1.0127	1.30	0.8771
0.630	1.2599	0.805	1.1146	0.980	1.0102	1.31	0.8737
0.635	1.2549	0.810	1.1111	0.985	1.0076	1.32	0.8704
0.640	1.2500	0.815	1.1077	0.990	1.0050	1.33	0.8671
0.645	1.2451	0.820	1.1043	0.995	1.0025	1.34	0.8639
0.650	1.2403	0.825	1.1010	1.00	1.0000	1.35	0.8607
0.655	1.2356	0.830	1.0976	1.01	0.9950	1.36	0.8575
0.660	1.2309	0.835	1.0944	1.02	0.9901	1.37	0.8544
0.665	1.2263	0.840	1.0911	1.03	0.9853	1.38	0.8513
0.670	1.2217	0.845	1.0879	1.04	0.9806	1.39	0.8482

COMPARISON OF DRYING AGENTS AND DEHYDRATION PROCESSES*

Type of dehydration	Advantages	Disadvantages	Remarks
PHYSICAL AND PHYSICOCHEMICAL METHODS			
Cooling	Inexpensive where cooling water is cheap or refrigeration is available as by-product of another process	Limited degree of dehydration. Possibility of plugging cooler tubes with ice or hydrates	
Compression		Possibility of hydrate formations in cooler. Not economical unless higher pressures are necessary for some other step in processing the gas	Dehydration plants follow compressors to take advantage of this effect
ABSORPTION WITH LIQUIDS			
Brine (35–40% $CaCl_2$)	$CaCl_2$ very cheap. Small make-up required (0.1–0.2 lb $CaCl_2$/million cu ft., 0.393 lb/million cu ft)	Danger of electrolytic corrosion (not corrosive in natural gas unless pH is below 4.2). Tends to emulsify with accumulated absorption oil, entrained oil, etc., to decrease the efficiency of contacting equipment. Available dew-point depression limited by the solubility of $CaCl_2$. Hydrogen sulfide forms objectionable precipitates	Dew-point depression of 23–31° F
Diethylene glycol 96%	Relatively stable toward gases containing oxygen, sulfur, or carbon dioxide. Good dew-point depression. No danger of solidification of concentrated solutions	0.2–0.8 lb glycol lost/million cu ft through vaporization	Dew-point depression of 40–60° F
Lithium chloride	Highly hygroscopic. Nontoxic. Not hydrolyzed on boiling. Concentrated solutions not readily solidified. Less corrosive than $CaCl_2$.	Expensive. Commercial grades of lithium chloride reported to be corrosive because of impurities	Dew-point depression of 40–67° F
Glycerin 85%		Expensive. Tends to decompose on regeneration. At concentrations above 85%, it becomes too viscous for easy handling and foams easily	Dew-point depression of 30–33° F. Used in manufactured gas plants abroad
Zinc chloride	High dew-point depression	Possible acid corrosion	Dew-point depression of 40–55° F
Calcium chloride, 40% Glycerin, 20%	Inhibits crystallization of $CaCl_2$, allowing greater dew-point depression than straight $CaCl_2$	Hydrogen sulfide forms iron sulfide and causes foaming. Corrosive	Dew-point depression of 23–41° F. 0.02 to 0.06 gal of make-up/million cu ft on unit treating 110–130 million cu ft/day at 200 psi
Dow 8A ($CaBr_2$-$CaCl_2$ and/or $CaBr_2$)	High dew-point depression	Corrosive	Dew-point depression of 29–64° F
Amine, glycol, water, 7–8% mono-ethanol-amine, 75–80% diethylene glycol, 12–16% water	Simultaneous removal of water, carbon dioxide, hydrogen sulfide, and other acid gases. Greater dew-point depression than glycol alone. Glycol reduces foaming tendencies of the amine	Amines volatilize and may be adsorbed on solid desiccants used in subsequent processing, necessitating occasional washing of the desiccant	Approximately 0.1 gal/million cu ft make-up required
WITH SOLIDS			
Lump $CaCl_2$. Molded from water, $CaCl_2$ and pulverized minerals or molten 72% $CaCl_2$ solution. Addition of pulverized carbon adds odor adsorption	Inexpensive. High capacity. Simple equipment required	Disintegrates in water, obstructing gas flow. Corrosive. Efficiency of dehydration varies with amount of water absorbed. Generally discarded when once exhausted	
Lump KOH, NaOH	(same advantages and disadvantages as lump $CaCl_2$)		Used for liquefied petroleum gases
Adsorption. Granular adsorbents in general (silica gel, activated alumina, activated $CaSO_4$, activated bauxite, Florite Desiccant)	Good drying efficiency. Not corrosive. Easily regenerated. Easily handled.	Drying unit is cyclic rather than continuous. May be plugged or disintegrated by contaminants. Relatively high heat requirements for regeneration	Dew-point depression of 100° F or more
CHEMICAL METHODS			
Phosphorus pentoxide, P_2O_5	Highest drying efficiency. Good capacity	Difficult to handle. Corrosive. Becomes wet and sticky when saturated. Strongly acid.	Not used on large-scale gas drying
Barium oxide, BaO. Precipitated by heating $BaCO_3$	Will dehydrate at temperature up to 1000° F. Cheap. Granular. Easily handled. Efficiency practically equal to P_2O_5. Large capacity.	Expands on hydration. Cannot be regenerated. Strong alkali.	
Magnesium perchlorate (anhydrous: trihydrate)	Anhydrous form reported to have efficiency of P_2O_5. Large capacity. Contracts on adsorbing water. Chemically neutral.	Not suitable for flammable or acid gases (reacts to form explosive perchloric acid	
Magnesium oxide, MgO	High activity	Low capacity	Not used on large-scale gas drying
Unslaked lime, CaO	High capacity	Corrosive. Hard to handle	
COMBINATION METHODS			
Combined absorption-adsorption (HiFlorite, alumina, $CaCl_2$, impregnated Drierite, etc.)	Relatively high capacity. Good efficiency	Loss of impregnated salt at high moisture saturation. Higher initial cost of desiccant. Corrosive (depending on nature of impregnated salt)	
Combined use of refrigeration and liquid absorbent	Higher dew-point depression than absorbent alone. Less danger of freeze-ups than refrigeration alone	Must be preceded by gasoline plant on natural-gas systems to prevent formation of condensate, relatively complex plant operation	

*Amero, Moore, and Cappell, *Chem. Eng. Progress*, April, 1947. Reproduced by permission of the authors, the Floridin Company, Warren, Pa., and the AIChE.

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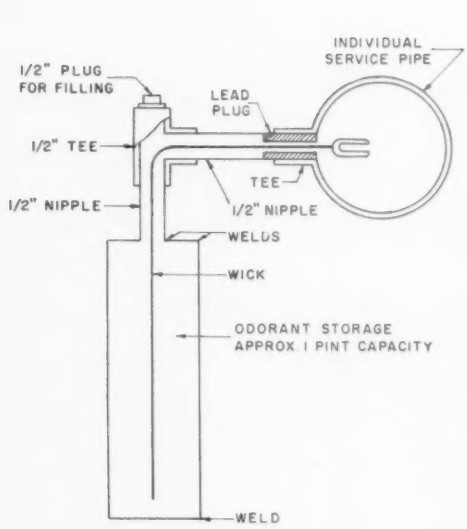
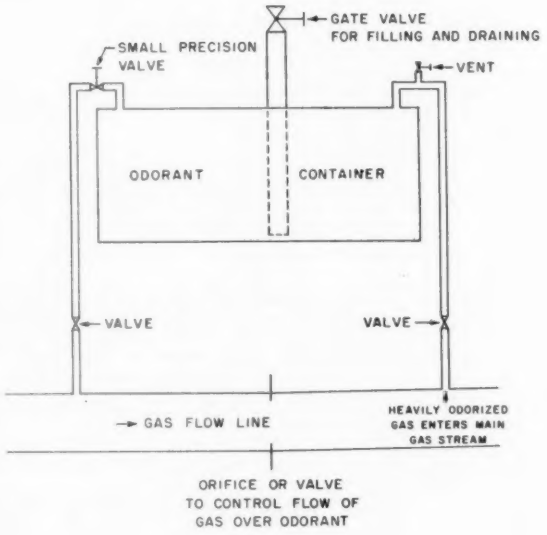


Wick type odorizer.



By-pass type odorizer.

Odorization of Natural Gas

THE lower explosive limit of natural gas is approximately 4 parts of gas and 96 parts of air. This explosive limit varies with the contents of the gas. Gas containing butane and propane mixtures in vapor form have a slightly lower explosive limit.

Odorants are added to natural gas to make possible its detection in mixtures below the lower explosive limit. Generally accepted practices of odorization require that the odor must be discernable in mixtures of from one half to one per cent of gas in air.

Two major types of odorants are in common use at the present time. These are known as **dilute** and **concentrated** odorants. The quantity of either type of odorant to be used can be determined only by a study of the conditions existing where it is to be injected into the gas.

Dilute odorants are used generally where the gas load is small, and the quantity of odorant handled is not a problem. Different odorants in this classification have varying characteristics, and should be injected within the ranges of manufacturers' recommendations.

Concentrated odorants are particularly adapted to large installations and by-pass odorizers. The proper odorant should be used for the type of equipment installed, as the concentration of the odorant will produce additional operating problems if improperly injected. The quantity of odorant used should be within the limits of manufacturers' recommendations and should be sufficient to provide a strong odor at the extremities of the system.

Odorizing equipment can be roughly classified into divisions as follows, with variations in each division, depending upon local conditions and standards:

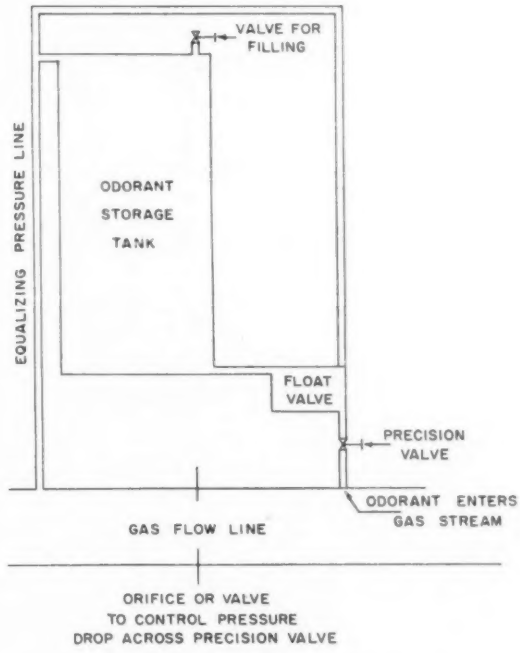
Wick Type Odorizer

This odorizer is particularly adapted to use where the odorizers must be installed on individual meters. This odorizer does not give proportional odorization because it is affected by the temperature and volatility of the odorant rather than by the gas load. The temperature effects on this odorizer can be reduced by surrounding it with asbestos insulation. Some insulation can be obtained by painting the odorizer with aluminum paint, or by protecting it from direct sunlight.

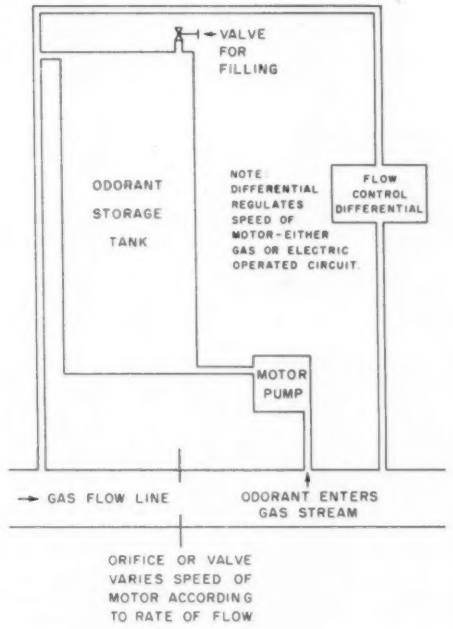
It may be necessary to drain the odorizer periodically in order to remove any accumulated heavy ends of odorant. The wick type odorizer is not recommended for larger installations where proportional odorization can be obtained by other methods. Either dilute or concentrated odorant can be used, as the odorant output is regulated by the amount of wick extending into the gas stream. Dilute odorant is generally preferred.

By-Pass Type Odorizer

This type odorizer will give porportional odorization under a wide range of loading, if properly designed and installed.



Proportional drip type odorizer.


VALVE FOR FILLING
ODORANT STORAGE TANK
NOTE DIFFERENTIAL REGULATES SPEED OF MOTOR-EITHER GAS OR ELECTRIC OPERATED CIRCUIT.
FLOW CONTROL DIFFERENTIAL
MOTOR PUMP
GAS FLOW LINE
ODORANT ENTERS GAS STREAM
ORIFICE OR VALVE VARIES SPEED OF MOTOR ACCORDING TO RATE OF FLOW

Liquid injection type odorizer.

It has no moving parts to get out of adjustment. Temperature variation of the odorant must be kept at a minimum, and it is recommended that the by-pass odorizer be installed underground with a minimum of two feet of cover. If possible it should be installed below (not across) a regulator in order to insure a constant pressure on the odorizer.

Liquid hydrocarbons entrapped in the gas will contaminate the odorant in a by-pass odorizer, reducing the volatility of the mixture, and slowing down the rate of odorization. Most gas from pipe line systems has had these liquids removed, so this problem generally exists only near gas fields.

The rate of flow is regulated by a small precision valve in the gas flow line over the odorant. A small pressure differential is maintained in the gas main, across a valve or orifice plate. Since the parallel flow in the two lines always remains proportional, the rate of odorization remains constant regardless of load (assuming constant pressure and temperature). No baffles or wicking should be installed in the odorizer, as the amount of gas passing over the odorant is very small in comparison to the ability of the odorant to be absorbed into the gas stream.

The odorant used in the by-pass odorizer must be blended especially for this type odorizer. It should be a concentrated odorant with a very narrow range from initial to final billing point. If the proper odorant is used, there should be no accumulation of heavy ends in the odorizer, but a connection to the bottom of the odorizer may prove valuable in case the odorant becomes contaminated.

Proportional Drip Type Odorizer

The elementary proportional drip type odorizer consists of a storage tank for odorant, a float valve to regulate the flow of odorant through a precision valve, and equalizing lines across a restriction in the gas main. This odorizer requires more pressure drop across the restriction than does the by-pass type. The precision valve acts as an orifice to keep the flow of liquid odorant and gas proportional. The float valve keeps a constant level of liquid on the precision valve, regardless of the quantity of odorant in storage.

This odorizer will operate with either dilute or concentrated odorant. At exeremely low rates of flow, it is necessary to cut down the flow of liquid through the precision valve to such an extent that stoppage may result, or the float valve may build up sufficient pressure to cause the odorant to flow when the gas flow has practically stopped, causing excess odorization. Under these conditions, better results may be secured if a dilute odorant is used.

The proportional drip type odorizer operates across a restriction in the gas line, and the precision valve controls the rate of odorization. Other features can be added if desired, to secure accurate rates of flow. Modifications of the odorizer have value under certain conditions. One modification permits the use of the storage tank as a by-pass odorizer during periods of low flow.

Liquid Injection Type Odorizer

A positive method of injecting odorant by means of a proportioning pump is in use. One odorizer uses a small, extremely accurate pump, which is installed in such a manner that it injects odorant proportionally to the load.

Another type has a proportionate amount of gas passing through a positive meter, activating a rotary cup, which dips odorant from a pan where the odorant level is kept constant by a float valve. The odorant is then dripped into the gas flow line in proportion to the load on the main line.

This type equipment will work with a variety of odorants, but since there are moving parts to stick, special attention must be paid to having a properly designed and clean odorant.

Conclusion

A properly blended odorant should give odorization thruout the entire system. The amount of sulfur in it is not sufficient to cause damage to gas meters or other equipment. The amount of sulfur added to the gas through odorization is far below the amounts of impurities carried in the normal gas stream.

Properties of Odorants for Natural Gas

(As of November, 1956, based on data supplied by the manufacturers)

Name of Odorant and Manufacturer	Specific Gravity	Mol. Wt. (avg.)	Weight Per Gal (lb.)	Viscosity Centistokes @ 77 F	Reid Vapor Pressure (psi @ 100 F)	Distillation	Volatility lb/MMcf)	Cloud Point	Freezing Point	Flash Point (Open Cup)	Mercaptan Content (% by vol.)	Sulfur Content (% by wt.)	Toxicity	Solubility in Water (% by vol.)	Recommended Odorizing Rate (lb/MMcf)	Sulfur Contribution (gr/100 cu ft)
SHARPLES CHEMICALS DIVISION, Pennsylvania Salt Mfg. Co.																
Spotleak 1008	0.827 (20/20 C)	76.5	6.75	0.635	5.33	1 BP—120 F 95%—270 F	—	—20 F (Max)	Below —103 F	Below Zero	94 (Min.)	33 (Min.)	Non-toxic at normal odorization levels	0.44	0.5	0.13
Spotleak 1009	0.809 (20/20 C)	88	6.73	0.795	4.9	1 BP—120 F 95%—180 F	—	—20 F (Max)	Below —103 F	Below Zero	94 (Min.)	35 (Min.)	Non-toxic at normal odorization levels	0.16	0.5	0.12
MARSHALL HYDE																
Formula 55	0.788 (60/60 F)	90	6.48	—	—	1 BP—140 F 95%—152 F EP—170 F	—	—	—40 F	—	87% by wt	30	Non-toxic	—	0.25 to 0.5	0.1 to 0.2
NATURAL GAS ODORIZING CO.																
Captan	0.835 (60/60 F)	82	7.0	0.548 (60 F)	5.0	1 BP—120 F 95%—265 F EP—340 F	80 @ 0° F & 400 psig	—20 F	Below —100 F	45 F	90	33	Negligible	Negligible	.25—1.0	.058 to .23
BP Captan	0.806 (60/60 F)	86	6.72	—	7.2	1 BP—136 F 95%—150 F EP—166 F	100 @ 0° F & 400 psig	—20 F	Below —40 F	—	100	34.1	Negligible	Negligible	.25—1.0	.058 to .23
RP Captan	0.817 (60/60 F)	96	6.80	—	6.8	1 BP—125 F 95%—260 F EP—360 F	—	0° F	— 40 F	—	80	33.3	Negligible	Negligible	.25—1.0	.058 to .23
Captan "99"	0.832 (60/60 F)	80	6.92	0.610 (60 F)	6.0	1 BP—125 F 95%—240 F EP—340 F	—	—20 F	Below —100 F	—	100	33	Negligible	Negligible	.25—1.0	.058 to .23
DL Captan	0.730 (60/60 F)	90	6.1	—	8.5	1 BP— 98 F 95%—340 F EP—380 F	—	0° F	Below —100 F	—	10	3.5	Negligible	Negligible	3.05—6.1	.075 to 0.15
CL Captan	0.778 (60/60 F)	90	6.48	0.625 (60 F)	8.5	1 BP— 98 F 95%—350 F EP—400 F	—	—20 F	—	—	Negligible	4.17	Negligible	Negligible	3.24—6.48	.095 to .190
NM Captan	0.823 (60/60 F)	88	6.85	—	8.3	1 BP—130 F 95%—260 F EP—240 F	—	—10 F	Below — 80 F	—	95	34	Negligible	Negligible	.25 to 1	.058 to .23
MacSniff	0.856 (60/60 F)	66	7.1	—	14.6	1 BP— 98 F 95%—120 F EP—460 F	—	—10 F	Below —100 F	—	Negligible	46	Negligible	Negligible	.25 to 1	.08 to .32
ORONITE CHEMICAL COMPANY																
Calodorant "C"	1.00 (60/60 F)	88	8.3	0.94	1.0	1 BP—232 F 95%—250 F EP—267 F	7.2 @ 0° F & 1000 psi	—	Below —150 F	Below 80 F	Nil	36.8	Non-toxic at normal odorization levels	0.07	0.5 to 1.0	0.13 to 0.26
Calodorant "C" Special	0.878 (60/60 F)	104	7.3	0.82	1.3	1 BP—200 F 95%—340 F EP—360 F	3.4 @ 0° F & 1000 psi	—	Below —150 F	Below 80 F	Trace	20.6	Non-toxic at normal odorization levels	0.06	1.0	0.14
Alert 80	0.829 (60/60 F)	77	6.9	0.48	9.0	1 BP—112 F 95%—189 F EP—221 F	12.5 @0° F & 1000 psi	—	Below —150 F	Below 80 F	95	42	Non-toxic at normal odorization levels	0.20	0.5 to 1.0	0.15 to 0.30
LPG	0.816 (60/60 F)	76	6.8	0.48	12.0	1 BP—124 F 95%—130 F EP—145 F	134 @ 0° F & 1000 psi	—	Below —150 F	Below 80 F	99	42.1	Non-toxic at normal odorization levels	0.17	1.0	0.30
Calodorant B-1	0.8338 (60/60 F)	—	—	—	—	1 BP—206 F 95%—206 F EP—295 F	18 @ 0° F & 1000 psi	23 F	—	—	—	32.8	—	—	—	0.246

DIMENSION DATA ON TELESCOPIC WET SEAL GAS HOLDERS

Capacity Thousand Cubic Feet	Number of Lifts	Tank Dimensions Diam.	Tank Dimensions Height	Number of Columns	Pressure Inflated with Air — LIFTS 1st	2nd	3rd	4th	All	Usual Conn. Diam.	FOUNDATION Diameter	Excavation Cu.Yds.	Concrete Cu.Yds.	Water Load per Sq. Ft. on Bottom	Water To Fill Tank Gallons
5	One	25'-0"	12'-6"	4	4.8"				4.8"	6"	27'-6"	69	54	767	45,000
10	One	32'-0"	15'-6"	4	5.1"				5.1"	6"	34'-6"	84	69	955	91,700
15	One	37'-0"	17'-0"	4	4.5"				4.5"	10"	39'-6"	96	81	1048	134,700
20	One	40'-6"	18'-6"	5	4.6"				4.6"	10"	43'-0"	105	90	1142	175,900
25	One	42'-0"	21'-3"	5	4.8"				4.8"	10"	44'-6"	109	94	1315	207,400
30	One	44'-6"	22'-6"	6	4.8"				4.8"	12"	47'-0"	134	108	1395	258,800
40	One	50'-6"	23'-0"	6	5.1"				5.1"	12"	53'-0"	164	138	1422	340,700
50	One	55'-6"	23'-8"	6	4.8"				4.8"	12"	58'-0"	168	142	1465	424,300
60	One	59'-6"	24'-6"	6	4.6"				4.6"	12"	62'-0"	189	155	1533	505,000
75	One	64'-0"	26'-3"	8	4.6"				4.6"	12"	66'-6"	198	172	1628	625,700
100	One	71'-3"	28'-0"	8	4.4"				4.4"	12"	73'-9"	226	200	1735	828,200
125	One	79'-3"	28'-0"	9	4.5"				4.5"	12"	81'-9"	259	233	1735	840,700
75	Two	50'-6"	23'-0"	9	5.6"				9.7"	12"	53'-0"	165	139	1422	340,700
100	Two	57'-5"	23'-10"	9	5.4"				9.1"	12"	59'-11"	190	164	1478	457,000
125	Two	62'-0"	25'-6"	9	5.9"				10.0"	12"	64'-6"	206	180	1582	570,200
150	Two	66'-6"	26'-0"	9	5.6"				9.4"	16"	69'-0"	248	208	1610	669,000
200	Two	73'-2"	28'-3"	9	5.2"				8.8"	16"	75'-8"	278	238	1752	882,000
250	Two	79'-8"	29'-9"	10	5.5"				9.1"	16"	82'-2"	308	268	1848	1,101,100
300	Two	84'-3"	31'-4"	10	5.5"				9.1"	16"	86'-9"	332	292	1945	1,294,900
400	Two	93'-3"	34'-0"	10	6.1"				9.9"	24"	95'-9"	403	348	2110	1,729,300
500	Two	102'-0"	35'-2"	12	5.4"				8.9"	24"	104'-6"	455	400	2185	2,134,300
300	Three	75'-0"	28'-3"	9	5.0"	8.3"			11.2"	16"	78'-0"	316	276	1752	925,300
400	Three	80'-0"	32'-4"	10	5.5"	9.1"			12.3"	24"	83'-0"	364	309	2010	1,206,100
500	Three	93'-9"	28'-10"	10	5.2"	8.2"			10.8"	24"	96'-9"	440	385	1788	1,475,600
600	Three	95'-4½"	34'-0"	10	6.1"	9.8"			13.0"	24"	98'-4½"	450	395	2110	1,805,000
750	Three	104'-7"	35'-0"	12	6.0"	9.6"			12.6"	24"	107'-7"	504	449	2170	2,240,600
1,000	Three	118'-6"	35'-9"	14	5.9"	9.5"			12.7"	24"	121'-6"	605	550	2220	2,928,700
1,500	Three	142'-5"	36'-3"	16	5.5"	8.7"			11.4"	30"	145'-5"	857	754	2250	4,293,700
1,000	Four	105'-0"	35'-0"	12	7.2"	11.1"	14.7"		17.9"	30"	108'-0"	605	502	2185	2,245,000
1,500	Four	136'-6"	30'-10"	14	5.5"	8.5"	11.2"		13.6"	30"	139'-6"	843	740	1915	3,350,000
2,000	Four	145'-5"	35'-8"	16	5.9"	8.6"	11.1"		13.0"	36"	148'-5"	976	863	2215	4,411,300
3,000	Four	175'-0"	36'-3"	18	5.5"	8.4"	11.0"		13.3"	36"	178'-0"	1253	1140	2250	6,477,000
5,000	Five	204'-4"	35'-9"	22	5.2"	7.5"	9.6"	11.7"	13.5"	36"	207'-4"	1613	1500	2220	8,709,700
6,000	Five	210'-2"	40'-6"	22	5.8"	8.1"	10.4"	12.5"	14.3"	42"	213'-2"	1739	1590	2520	10,477,300
8,000	Five	240'-9"	40'-4"	24	6.0"	8.3"	10.5"	12.7"	14.5"	42"	243'-9"	2129	1980	2500	13,670,800
10,000	Five	276'-6"	38'-2"	28	5.1"	7.0"	8.7"	10.4"	14.7"	42"	279'-6"	2639	2490	2375	17,031,300

ANALYSES OF COAL TYPES FREQUENTLY USED IN, OR SUITABLE FOR BY-PRODUCT COKE OVENS[1]

Name of coal	Proximate analysis (on coal as received)			Ultimate analysis (on dry coal)						Btu value (dry coal)	Estimated coke yield (total), per cent on coal as received	Estimated gas yield, Btu in gas per lb coal
	Moisture	Volatile matter	Fixed carbon	Ash	Carbon	Hydrogen	Oxygen	Sulphur	Nitrogen			
Pennsylvania:												
Connellsville[3]	2.40	31.00	61.38	7.22	78.50	4.67	6.82	0.97	1.62	14,230	71.0	3,100
Lower Connellsville	2.00	32.20	58.00	7.80	77.80	5.20	6.33	1.09	1.63	14,100	70.0	3,200
Westmoreland	1.00	35.00	57.60	6.40	79.60	5.36	6.14	0.90	1.60	14,320	68.0	3,350
Pittsburgh[3]	3.03	35.22	55.36	6.39	79.45	5.34	5.94	1.23	1.45	14,230	68.5	3,300
Freeport[3]	2.66	34.35	56.42	6.57	79.13	5.34	6.18	1.02	1.58	14,180	69.0	3,300
Somerset (Orenda)[2]	3.77	16.26	71.06	8.91	81.96	4.15	2.22	0.81	1.60	14,075	81.0	2,600
Clearfield—Cambria (Lower Kittanning)[3]	2.00	21.17	70.90	5.93	84.10	4.60	2.72	1.23	1.42	14,800	78.5	2,680
West Virginia:												
Boomer[3]	2.96	33.57	59.18	4.29	82.45	5.32	5.36	0.80	1.65	14,840	69.0	3,300
Cabin Creek (Kanawha)	2.70	31.30	59.79	6.21	80.38	4.69	6.79	0.59	1.17	14,600	71.0	3,300
No. 2 gas[3]	2.52	34.86	56.42	6.20	80.86	5.15	5.16	0.87	1.60	14,500	69.0	3,300
Fairmont[3]	2.51	37.66	53.25	6.58	78.63	5.29	6.56	1.23	1.54	14,130	66.0	3,350
Pocahontas[3]	2.60	16.39	76.38	4.63	86.79	4.22	2.33	0.78	1.13	15,020	81.0	2,650
New River[3]	3.51	24.76	69.00	2.73	86.08	4.95	3.91	0.60	1.63	15,220	75.0	2,750
Elkins[3]	1.40	26.40	62.92	9.28	79.03	4.74	3.85	1.52	1.45	14,020	75.0	2,850
Virginia:												
Tasewell Co. (Seaboard)[3]	3.13	29.00	61.77	6.10	82.63	4.82	4.23	0.60	1.42	14,670	71.0	3,100
Toms Creek[3]	2.29	32.87	59.62	5.22	82.67	5.05	4.78	0.55	1.61	14,810	70.0	3,200
Wise Co. (Roda)	2.00	34.90	60.90	2.20	84.50	5.27	5.85	0.55	1.63	14,990	69.0	3,300
Eastern Kentucky:												
Elkhorn[3]	2.91	36.33	57.53	3.23	82.26	5.49	6.71	0.57	1.64	14,650	66.0	3,450
Coxton[3]	3.18	37.21	56.30	3.31	81.50	5.30	7.10	0.96	1.72	14,620	65.0	3,450
Benham[3]	2.50	37.52	57.63	2.35	83.01	5.42	7.07	0.53	1.56	14,960	65.5	3,500
Tennessee:												
Jellico[3]	3.87	38.03	55.18	2.92	80.34	5.54	7.90	1.13	2.05	14,250	63.0	3,400
Alabama:												
Pratt Seam[3]	2.20	28.83	62.88	6.09	81.69	4.97	3.86	1.66	1.59	14,550	72.0	3,000
Tuscaloosa[3]	2.62	24.18	64.11	9.09	79.61	4.55	4.33	0.66	1.52	14,090	75.0	2,700
Illinois:												
Franklin Co. (Orient)[3]	9.93	33.13	48.77	8.17	74.47	4.84	9.22	0.83	1.57	13,200	61.0	2,900
Indiana:												
Ayrshire[3]	12.31	35.05	46.54	6.10	75.87	5.19	9.15	1.11	1.72	13,530	60.0	2,950
Colorado:												
Trinidad[3]	4.20	36.51	52.03	7.17	77.24	5.12	8.09	0.61	1.45	13,670	64.0	3,150
Utah:												
Sunnyside[3]	4.06	37.99	49.89	8.06	74.95	5.43	8.49	1.20	1.53	13,380	63.0	3,200
Washington:												
Rosslyn	3.77	37.69	47.05	11.49	72.92	5.36	7.71	0.49	1.58	13,262	63.0	3,100

Most of these analyses except where noted are of face samples taken in the mine; usually car deliveries to the consumer run 2% to 3% higher in ash.
[1] Prepared by Dr. H. C. Porter, Consulting Engineer, Philadelphia.
[2] Mine sample, analysis by U. S. Bureau of Mines.
[3] Car sample, average of 10 cars, analysis by U. S. Bureau of Mines.

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PRODUCTS OF HI AND LOW TEMPERATURE CARBONIZATION

Yields of High Temperature, Low Temperature and Complete Gasification Processes

Process	Yield ammonium sulphate	Yield light oil benzol tobol, xyol	Yield tar	Yield gas	Yield coke
High temperature Distillation	20–24 lbs. Per ton	3 plus gals. Per ton	8–12 gals. Per ton	10,000–11,500 Cu. ft. per ton 500–560 Btu per cu. ft.	1300–1400 lbs. per ton Suitable for metallurgical processes and domestic fuel
Low temperature Distillation	16–20 lbs. Per ton	3–5 gals. Per ton	20–28 gals. Per ton	5000–6000 Cu. ft. Per ton 500 to 900 Btu per cu. ft.	1400 lbs. plus per ton Domestic fuel may have to be briquetted
Complete Gasification	75 lbs. Per ton	1 gal. plus Per ton	25 gals. Per ton	100,000 Cu. ft. plus Per ton below 200 Btu's per cu. ft.	None

AVERAGE FLUE GAS DEW POINT FOR VARIOUS FUELS*

Fuel	Average dew point (temperature, °F)
Anthracite	68
Semi-bituminous coal	84
Bituminous coal	93
Oil	111
Natural gas	127
Manufactured gas	137
Propane (2,500 Btu per cu. ft)	119
Butane gas (3,200 Btu per cu. ft)	124
Butane-air gas mixture (535 Btu per cu. ft)	121

* American Society for Testing Materials.

OPERATING RESULTS, BY-PRODUCT COKE OVENS[1]

	Utica	Philadelphia
Coal used, per cent volatile matter (ash- and moisture-free)[2]	37.8	30.1
Coal charge, tons	6.86	17.9
Coking time (avg.), hr (gross)	12.6	16.46
Width of ovens (avg.), in.	13½	17¼
Coke yield, per cent dry	70.2	74.0
Gas, cu ft per lb dry coal	5.66	5.36
Gas, Btu per cu ft	584	577
Gas, Btu per lb dry coal	3,305	3,093
Producer fuel, dry, per ton coal, lb	292	215
Producer fuel, combustible, per ton coal, lb	253	200
Producer fuel used, cu ft per lb coal (at 130 Btu)	9.99	7.52
Yield tar, gal per ton	12.35	8.16
Yield sulphate, lb per ton	24.68	20.92 (Diluted with 11% producer gas)
Gas analysis:		
CO_2, per cent	2.2	1.8
Ill., per cent	4.0	3.3
O_2, per cent	0.8	0.3
CO, per cent	6.3	8.5
CH_4, per cent	32.1	24.7
H_2, per cent	46.5	51.0
N_2, per cent	8.1	10.4
	100.0	100.0

Data assembled by H. C. Porter, Philadelphia.

[1]Actual plant data submitted by The Koppers Company, Pittsburgh, Pa., for two plants, Utica, N. Y. (consisting of 21 small-size ovens built in 1924), and Philadelphia, Pa. (consisting of 74 large-size ovens built in 1928), both plants being Becker type Koppers ovens, fired by producer gas. The Utica results are taken from the official report of A.G.A. Carbonization Plant Tests made in 1925 for comparison of different types of plant, operating on the same coal. The Utica ovens were the first of their size and type to be built and on that account were not operating at the time to the best advantage. The Utica results cover a period of 21 days. The Philadelphia results are averages for a five-month period.

[2]At Utica, 100 per cent volatile Pittsburgh coal; at Philadephia a mixture averaging 76 per cent Powellton (W. Va.) and 24 per cent Pocahontas.

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CALCULATING HEATING VALUE OF COAL FROM ANALYSIS

By far the most satisfactory way of determining the heating value of a coal is by the bomb calorimeter. Where only the analysis is available the following computations of the approximate heating value of the coal may be made.

Ultimate Analysis:

$$\text{Btu per lb} = 146\,C + 620\left(H - \frac{O}{8}\right) + 40.5\,S$$

where

C = per cent of carbon.
H = per cent of hydrogen.
O = per cent of oxygen.
S = per cent of sulfur.

With bituminous and anthracite coals and calculated values will usually be within 1½ per cent of the observed value. The higher the percentage of oxygen the greater is the error apt to be.

Proximate Analysis:

$$\text{Btu per lb} = (C \times c + V \times v) - (16\,M + 30\,A + 39\,S)$$

where

C = per cent of fixed carbon.
V = per cent of volatile combustible.
M = per cent of moisture.
A = per cent of ash.
S = per cent of sulfur.
c — see Table I.
v — see Table II.

TABLE I Values of c.

For Anthracite Coal	141
For Bituminous Coal	140
For Lignite	95
For Coke	130

Table II Values of v .

Per cent vol. comb.	"v"	Per cent vol. comb.	"v"
1	240.5	27	180.5
2	236.4	28	178.8
3	232.5	29	177.2
4	228.8	30	175.5
5	225.3	31	173.9
6	221.9	32	172.3
7	218.6	33	170.7
8	215.4	34	169.2
9	212.3	35	167.8
10	210.3	36	166.6
11	208.3	37	165.5
12	206.4	38	164.4
13	204.6	39	163.3
14	202.7	40	162.2
15	200.9	41	161.1
16	199.2	42	160.0
17	197.5	43	158.9
18	195.7	44	157.8
19	194.0	45	156.7
20	192.3	46	155.6
21	190.6	47	154.5
22	188.9	48	153.4
23	187.2	49	152.3
24	185.5	50	151.2
25	183.8	51	150.1
26	182.1	52	149.0

H. H. Clark—American Gas Light Journal.

ANALYSES AND PHYSICAL PROPERTIES OF PETROLEUM OILS

Source or name	Gravity, °Be	Sp gr 60°/60°F	Analysis					Btu per lb	Flash point, open cup, °F	Fire point, °F	Viscosity	
			C	H	O and N	S	H_2O				Saybolt seconds at 70°F	Engler scale at 68°F
Crude oils:												
Western	14.4	0.970	85.64	11.37	0.84	1.06	...	18,478	192	...	387	.....
Kern River, Calif.	15.0	0.966	.....	.....	....	0.89	0.5	18,500	102	128	...	690.0
Summerland, Calif.	15.1	0.965	.....	.....	....	0.36	1.2	18,530	100	130	...	222.1
Los Angeles City, Calif	15.4	0.963	.....	.....	....	0.62	1.7	18,430	107	145	...	272.5
Salt Lake, Calif.	15.7	0.961	.....	.....	....	2.29	0.9	18,230	46	89	...	574.3
Western	16.4	0.957	86.58	11.61	0.74	0.82	...	18,613	172	...	380	.....
Western	17.4	0.950	86.37	11.30	1.14	1.60	...	18,727	230	...	250	.....
Sunset, Calif.	18.1	0.946	.....	.....	....	0.89	0.5	18,605	47	79	...	120.5
Coalinga, Calif.	19.4	0.938	.....	.....	....	0.48	0.4	18,550	70	93	...	80.7
Whittier, Calif.	19.4	0.938	.....	.....	....	0.61	0.0	18,810	46	84	...	34.6
Lompoc, Calif.	20.0	0.934	.....	.....	....	3.55	0.7	18,330	−1	21	...	62.5
Midcontinent	20.2	0.933	86.06	11.21	2.06	0.67	...	19,440	273	...	220	.....
Midway, Calif.	20.5	0.931	.....	.....	....	0.66	0.6	18,710	54	83	...	91.7
Texas	21.6	0.924	84.60	10.90	2.87	1.63	...	18,977	60	...	...	.....
Newhall, Calif.	22.1	0.921	.....	.....	....	0.35	0.2	18,890	60	83	...	118.2
Midcontinent	22.4	0.920	84.60	10.90	2.87	1.63	...	19,060	180	...	198	.....
Fullerton, Calif.	22.5	0.919	.....	.....	....	0.89	0.2	18,800	18	52	...	110.5
Pennsylvania	23.3	0.914	86.10	13.90	....	0.60	...	20,752	...	...	...	.....
Midcontinent	24.2	0.909	87.93	11.27	0.19	0.41	...	19,650	264	...	188	.....
Coyote Hills, Calif.	24.9	0.905	.....	.....	....	1.14	tr.	18,965	27	50	...	10.5
Santa Fe Springs, Calif.	34.8	0.851	.....	.....	....	0.45	...	.....	...	...	50	.....
Santa Fe Springs, Calif.	27.9	0.888	.....	.....	....	0.54	...	.....	...	...	105	.....
Santa Maria, Calif.	24.9	0.905	.....	.....	....	1.93	0.1	18,710	−2	20	...	19.0
Santa Paula, Calif.	25.5	0.901	.....	.....	....	0.54	0.5	18,840	6	18	...	5.8
Sespe, Calif.	26.6	0.895	.....	.....	....	0.34	0.4	18,990	18	40	...	10.8
Eastern	31.9	0.866	86.40	12.37	1.02	0.13	...	19,890	102	...	165	.....
Kansas	31.9	0.866	85.40	13.07	....	.....	...	20,345	...	...	...	.....
West Virginia	36.8	0.841	84.30	14.10	1.60	.....	...	20,818	...	...	...	.....
Pennsylvania	37.2	0.839	.....	.....	....	.....	...	20,560	128	180	...	.....
Ohio	39.4	0.829	85.00	13.80	0.60	0.60	...	20,752	...	...	...	.....
Eastern	40.4	0.823	82.00	14.80	3.20	0.10	...	20,300	78	...	112	.....

									Closed cup		Saybolt seconds	at °F
Fuel oils:												
Mexican	10.0	1.000	88.05	7.58	1.00	3.28	...	17,500	374	...	322	250
Bakersfield, Calif.	11.1	0.992	.....	.....	....	....	1.3	18,257	...	...	...	.....
Mexican	11.9	0.987	86.90	9.36	....	3.16	...	18,050	310	...	300	250
Los Angeles, City, Calif.	13.4	0.977	.....	.....	....	.....	0.4	18,280	...	...	...	.....
Bakersfield, Calif.	13.6	0.975	.....	.....	....	.....	...	17,600	.....	...	...	.....
California	13.6	0.975	.....	.....	....	2.46	1.3	18,104	...	...	...	.....
Mexican	14.1	0.971	85.26	10.31	....	3.94	...	18,260	208	...	92	220
California	15.0	0.966	81.52	11.61	6.92	0.55	...	18,926	...	...	...	.....
Los Angeles City, Calif.	16.4	0.957	.....	.....	....	.....	...	18,855	196	...	...	.....
Midcontinent	16.7	0.955	83.22	10.16	3.74	2.83	...	18,427	190	...	74	220
Kern River, Calif.	17.4	0.950	.....	.....	....	.....	...	18,845	140	...	...	.....
Whittier, Calif.	17.9	0.947	.....	.....	....	.....	...	17,822	148	208	...	.....
Western	18.1	0.946	86.11	11.81	1.20	0.67	...	18,790	186	...	750	100
Whittier, Calif.	18.4	0.944	.....	.....	....	1.98	1.1	18,507	...	...	...	.....
Beaumont, Texas	18.7	0.942	86.1	12.3	....	1.60	...	20,152	...	...	...	.....
Sabine, Texas	19.5	0.937	.....	.....	....	.....	...	18,662	143	...	...	.....
Whittier, Calif.	19.7	0.936	.....	.....	....	0.72	1.1	18,240	...	...	...	.....
Saratoga, Texas	20.6	0.930	.....	.....	....	.....	...	19,665	180	242	...	.....
Coalinga, Calif.	21.1	0.927	.....	.....	....	.....	...	17,117	134	...	...	.....
Humble, Texas	21.3	0.926	.....	.....	....	.....	...	19,649	166	214	...	.....
Beaumont, Texas	21.6	0.924	84.6	10.9	2.87	1.63	...	19,060	180	...	...	.....
Spindle Top, Texas	22.0	0.922	.....	.....	....	.....	...	19,663	165	219	...	.....
Mexican	22.1	0.921	.....	.....	....	.....	...	18,840	162	...	...	.....
Saratoga, Texas	22.4	0.920	.....	.....	....	.....	...	19,263	161	226	...	.....
Humble, Texas	22.4	0.920	.....	.....	....	.....	...	18,040	124	228	...	.....
Midcontinent	22.4	0.920	83.26	12.41	3.83	0.59	...	19,430	181	...	389	100
Spindle Top, Texas	22.6	0.918	.....	.....	....	.....	...	19,720	163	212	...	.....
Texas	24.0	0.910	87.29	12.32	....	0.43	...	19,659	375	...	...	.....
Texas	24.3	0.908	87.15	12.33	....	0.32	...	19,338	370	...	...	.....
Midcontinent	24.5	0.907	85.40	13.07	1.12	0.15	...	19,235	179	...	350	100
Louisiana	24.7	0.906	.....	.....	....	.....	...	19,908	192	219	...	.....
Louisiana	24.9	0.905	.....	.....	....	.....	...	20,193	194	233	...	.....
Beaumont, Texas	25.2	0.903	.....	.....	....	.....	...	19,349	222	...	...	.....
Kansas	25.5	0.901	.....	.....	....	.....	...	18,714	157	208	...	.....
California	27.3	0.891	.....	.....	....	.....	...	18,655	257	...	...	.....
Pennsylvania	27.8	0.888	.....	.....	....	.....	...	19,700	232	280	...	.....
Pennsylvania	28.0	0.886	84.9	13.7	1.4	.....	...	19,210	...	...	...	.....
Midcontinent	28.6	0.884	84.90	13.70	1.40	0.37	...	19,312	175	...	290	100
Colorado	29.1	0.881	.....	.....	....	.....	...	18,103	164	205	...	.....
Kansas	30.6	0.870	.....	.....	....	.....	...	19,210	130	181	...	.....
Indiana	32.1	0.865	.....	.....	....	.....	...	19,400	212	318	...	.....
Midcontinent	32.3	0.864	84.82	13.09	2.05	0.36	...	19,511	160	...	76	100
Midcontinent	35.9	0.845	84.36	13.21	1.09	0.32	...	19,627	154	...	42	100
West Virginia	36.8	0.841	84.3	14.1	1.6	.....	...	21,240	...	...	...	.....
Pennsylvania	37.6	0.837	.....	.....	....	.....	...	19,700	232	280	...	.....
Asphalt oil	13.4	0.977	.....	.....	....	.....	...	20,442	...	376	...	.....
Gas oil	16.2	0.958	86.16	9.05	3.06	0.30	...	16,960	195	...	98	220
Steamer oil	21.1	0.927	.....	.....	....	.....	...	29,291	268	322	...	.....
Kerosene, 150°	47.4	0.791	85.16	14.33	0.51	.....	...	19,922	110	...	...	.....
Oil tar	...	1.150	92.00	6.13	0.22	0.33	...	17,300	485	...	418	220
Coal tar	...	1.250	89.20	4.95	5.27	0.56	...	15,800	530	...	490	220

[1] Compiled from Gebhardt, "Steam Power Plant Engineering"; Babcock & Wilcox Company, "Steam"; Heine Safety Boiler Company, "Steam Boiler Engineering"; Report of Committee on Petroleum, 1917; Rufus T. Strohm, "Oil Fuel for Steam Boilers."

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CHARACTERISTICS OF CARBURETING OILS[1]

Sample designation	Gas oil (A)	Gas oil (B)	Gas oil (C)	Heavy oil (1)	Heavy oil (2)	Heavy oil (3)	Heavy oil with some cracker tar (4)	Heavy oil containing cracker tar (5)
A.P.I. gravity at 77°F	35.1	32.5	30.3	21.1	17.2	15.4	17.3	13.9
Coke, per cent	0.22	0.62	0.02	3.98	9.05	7.10	4.62	4.11
Sulphur, per cent	....	....	....	1.18	2.77	0.60	0.98	0.58
Distillation test:								
Per cent by volume								
Below 400°F	1.3	1.4	0.9					
400 to 450	15.8	7.0	10.0					
450 to 500	26.0	15.3	26.0	.....	0.6	.....	4.5	3.9
500 to 550	20.9	18.9	31.9	1.6	2.9	2.0	11.0	12.4
550 to 600	14.8	17.4	16.7	5.2	5.6	4.3	12.4	16.0
600 to 650	8.6	13.3	8.3	9.1	22.2	12.1	16.1	15.4
650 to 700	6.7	9.5	2.5	26.8	24.2	31.9	14.4	16.0
700 to 750	5.6	8.2	3.5	14.0	.....	32.1	30.0	20.2
Residue and loss	0.3	2.0	0.2	43.3*	44.5†	17.6	11.6	16.1
Below 600°F	78.8	60.0	85.5	6.8	9.1	6.3	27.9	32.3
Above 600°F	20.9	38.0‡	14.3	49.9	46.4	66.1	60.5	51.6
Hydrocarbon test:								
Per cent by volume								
Paraffins	73.0	45.0	44.6	49.0	32.0	34.9	48.3	35.7
Napthenes	9.0	19.0	43.0	23.0	48.0	36.3	21.7	27.9
Aromatics	4.0	10.0	8.0	8.4	0.8	12.0	12.0	14.4
Olefins	14.0	26.0	4.4	19.6	19.2	16.8	18.0	22.0
Saturated compounds	82.0	64.0	87.6	72.0	80.0	71.2	70.0	63.6
Aromatics and unsaturates	18.0	36.0	12.4	28.0	20.0	28.8	30.0	36.4
Cracking test:								
Optimum temperature, °F	1330–1390	1380–1425	1380–1410	1350–1500	1350–1450	1300–1450	1350–1450	1300–1425
Btu in gas per gal	104,000	101,500	96,500	108,100	96,900	96,000	84,000	74,500
Btu of oil per cu ft	1,750	1,750	1,595	1,775	1,870	1,741	1,705	1,770
Cu ft of oil gas per gal	59.5	58.0	60.5	60.8	51.8	55.1	49.3	42.0

[1]Jerome J. Morgan, "American Gas Practice."
*Begins to crack at 705 F.
†Decomposes at 672 F.
‡Includes 7.0 per cent distilling between 750 and 817 F.

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GAS OIL EFFICIENCY

Where gas oil is used for enriching carburetted water gas and no blow-run is made the following formula is generally employed to show the enriching value of the oil in Btu per gallon.

$$\text{Btu per Gal} = \frac{1000\,(F - B)}{G} + OB$$

where

F = Btu per cu ft of the finished carburetted water gas.

B = Btu per cu ft of the blue gas. (In lack of definite information frequently assumed to be 300.)

G = Gallons of oil per thousand cubic feet.

O = Cubic feet of oil gas produced per gallon of oil. (This is generally from 65 to 70 cu ft.)

INTERCHANGEABILITY OF VARIOUS GASES

Interchangeability of gases is the use of a substitute gas for the gas usually distributed for domestic and industrial consumption without interfering with the operation of appliances used by the consumer.

The subject is complicated by many factors such as heating value, specific gravity, and composition of the various gases under consideration.

The present supply of natural gas has resulted in the distribution in many cities of gases of rather high heating values; in many cases, of straight natural gas having a heating value in excess of 1000 Btu per cubic foot.

The American Gas Association has found that none of the formulae developed earlier for the interchangeability of mixed gases of lower heating value were applicable to the interchangeability of the higher heating value gases. New equations, which would take into consideration all factors affecting interchangeability, have been developed.

Interchangeability Factors

The interchangeability of higher heating-value gases is considered from three distinct viewpoints — the tendency of high heating value supplemental gases to —

1. Lift
2. Flashback
3. Produce yellow tips

The index of lifting interchangeability, I_L, is the result obtained from calculation of the lifting interchangeability equation:

$$I_L = \frac{K_s}{\frac{f_s}{f_a}\,\frac{a_s}{a_a}\left(K_s\text{-log}\,\frac{f_a}{f_s}\right)}$$

Type of Natural Gas Distributed

The American Gas Association assumes that one of the three types of natural gas presented below would be the gas normally distributed.

		High btu nat. gas	High methane nat. gas	High inert nat. gas
Carbon dioxide	CO_2	0.5%	0.0%	0.5%
Methane	CH_4	83.0	94.5	71.4
Ethane	C_2H_6	16.0	0.0	14.0
Propane	C_3H_8	0.0	0.0	1.0
Nitrogen	N_2	0.5	5.5*	13.1
B.t.u. per cu. ft		1115	959	1000
Sp. gr.		0.64	0.56	0.69

* Inerts.

For any proposed adjustment, or substitute gas, all three indices must fall within certain numerical limits, which are shown in an accompanying table.

Interchangeability index	High-heating value nat. gas		High-methane nat. gas		High-inert nat. gas	
	Perferable	Objectionable	Perferable	Objectionable	Perferable	Objectionable
I_L	Under 1.0	Above 1.12	Under 1.0	Above 1.06	Under 1.0	Above 1.03
I_F	Under 1.18	Above 1.2	Under 1.18	Above 1.2	Under 1.18	Above 1.2
I_Y	Above 1.0	Under 0.7	Above 1.0	Under 0.8	Above 1.0	Under 0.9

AGA "Index C" Method

The American Gas Association "Index C" is a criteria developed for the interchangeability of gases with heating values below 700 Btu per cubic foot. If the supplemental gas has a "C" index in the range 0.85 to 1.15, it is considered that it could replace the base gas and maintain satisfactory appliance performance.

An empirical expression, I_F, denotes the tendency of burners to flashback as a result of interchanging a supplemental gas for natural gas.

$$I_F = \frac{K_s}{K_a}\,\frac{f_s}{f_a}\,\sqrt{\frac{h_s}{1000}}$$

Equation for I_Y takes into consideration changes in primary-air injection and yellow-tip limit resulting from substitution of one gas for another.

$$I_Y = \frac{f_s}{f_a}\,\frac{a_a}{a_s}\,\frac{Y_s}{Y_s}$$

Values for Equation Characters

In order to obtain values for the characters in these three equations, certain other equations must be employed, as follows:

Air theoretically required for complete combustion,

$$\text{per 100 Btu } a_a = \frac{100\,A_a}{h_a}$$

$$\text{Primary air factor } f_a = \frac{1000\sqrt{d_a}}{h_a}$$

$$\text{Lifting limit constant } K_a = \frac{F_a}{d_a}$$

$$\text{Yellow-tip limit } Y_a = \frac{100\,T_a}{A_a + 7E_a - 26.3\,O_{2a}}$$

The nomenclature for the above equations follows—

A = air theoretically required for complete combustion. cubic feet per foot of gas
a = air theoretically required for complete combustion. cubic feet per 100 Btu of gas
d = specific gravity (air = 1.0)
E = total inerts in gas mixture, decimal volume
F = lifting constant
f = primary-air factor
h = gross heating value, Btu per cubic foot
I_F = index of flashback interchangeability
I_L = index of lifting interchangeability
I_Y = index of yellow-tip interchangeability
K = lifting-limit constant
O_2 = oxygen in gas mixture, decimal volume
T = yellow-tip constant, cubic feet of air required to eliminate yellow tips per cubic foot of gas
Y = yellow-tip limit, per cent primary air
Subscript a = adjustment gas
Subscript s = substitute (or supplemental) gas.

The equation is—

$$C = \frac{h_s}{h_a}\,\frac{A_s}{A_a}\,\frac{d_a}{d_s} + (K_a - K_s)$$

where,

C = index of interchangeability
a = subscript denoting adjustment gas
s = subscript denoting substitute gas

h = gross heating value, Btu per cubic foot

A = air theoretically required for complete combustion, cubic feet per cubic foot of gas

d = specific gravity of gas (air = 1.0)

$K = \frac{hA}{5000\ E\ F}$ in which

E = the heat capacity of the theoretical products of combustion (from one cubic foot of gas) per degree F between 60 F and 1600 F, in Btu E is equal to 0.029 VCO_2 + 0.0023 VH_2O + 0.0189VN_2 where V is the volume in cubic feet of each product (as indicated by the subscripts) formed by the combustion of one cubic foot of gas with the air theoretically required for complete combustion. The values 0.029, 0.023 and 0.0189 are, respectively, the heat capacities per degree F of CO_2, H_2O, and N_2, between 60 F and 1600 F in Btu per cubic foot.

F = Summation of the products of the mole fractions and some constant for each combustible constituent in the gas.

Disadvantages of "Index C" Equation

Several disadvantages are cited against the used of "Index C" in some cases.

1. It does not apply for mixtures in which the percentage of inerts exceeds the free-hydrogen content.

2. It is not generally applicable for mixtures involving adjustment and substitute gases of widely differing heating value or chemical composition unless the fraction of such radically differing gas in the substitute mixture does not exceed about 12 per cent. Thus the formula does not hold for such substitute mixtures as propane or butane and air, of natural gas inert mixtures, etc.

3. The formula does not usually apply in cases involving the use of large amounts of oil gases as substitutes for natural gas.

4. It is not fully applicable for gases of heating values higher than 800 Btu per cubic feet since the equation has no factors which predict the occurrence of yellow tips or lifting.

In 1946, the Amercan Gas Assocation started a new series of tests on the interchangeability of gases of relatively low heating value.

Knoy Formula

Several simple formulas have been proposed for use in determining the interchangeability of gases. The most well known is the Knoy formula, which is as follows:

$$C = \frac{H - 180}{\sqrt{G}}$$

C = a constant

H = heating value of gas, Btu per cubic foot

G = specific gravity of gas (air = 1)

180 = the heating value in Btu per cubic foot of the primary air-gas mixture which is assumed to be the proper adjustment for domestic burners.

The theory of this fromula is that gases which have the same "C" factor are interchangeable. Actually the normal flexibility of most domestic-appliance burners allows some variation in the "C" factor. This deviation will not usually exceed 10 per cent up or down from the "C" factor of the adjustment gas. "C" factor for substitute gases which are above that of the adjustment gas indicate softer types of flames, while harder flames are indicated if the "C" factor is found to be below that for the adjustment gas.

It has been stated that the results obtained by the use of the Knoy formula may be misleading if the chemical composition of the substitute gas does not correspond to that of the adjustment gas, and as a rule, limit mixtures defined by means of AGA Index C are considered to be more reliable than those indicated by the Knoy formula.

New Test Burners Devised

Many test burners have been devised to assist in evaluating the interchangeability of gases by observation of flame characteristics. At the present time there is no available instrument which can be applied in all cases to evaluate the gas quality. In approaching a problem involving interchangeability of gas, it is desirable to make calculations first, using the interchangeability equations and then burn the prepared mixtures in appliances having burners characteristic of those used in the community to be certain that the substitute gases will actually burn satisfactorily.

It is desirable that gas companies keep a control burner at the inlet and outlet of their gas-storage holders in order that they may, at all times, have a knowledge of the burning characteristics of the gas being produced and sent out.

Oil Gas Not Complete Replacement

It can be stated that high Btu oil gas, as now known, cannot be used as complete replacement for natural gas. However, some 30 to 60 per cent of these high Btu oil gases can be used in admixture with natural gas without excessive complaints from the consumers of the gas.

It must be pointed out that in some cases substitute gases appear to be entirely satisfactory from the standpoint of visual flame characteristics, but the products of combustion may contain dangerous quantities of carbon monoxide.

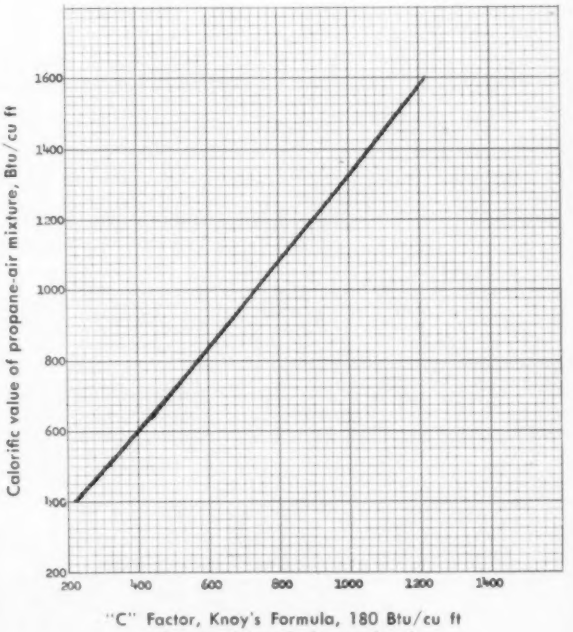
Determination of Proper Btu Value of Propane-Air Gas to be Used as a Substitute Gas

Procedure for calculating proper propane-air gas:

1) Determine "C" factor original gas from the following formula:

$$C = \frac{\text{Btu} - 180}{\sqrt{\text{Sp. Gr.}}}$$

2) Read chart for proper propane-air gas for "C" factor calculated



GAS COMBUSTION CONSTANTS

No.	Gas	Formula	Lbs per cu. ft.	Cu. ft. per lb	Sp. gr. Air = 1.000	Heat of combustion: Btu per cu. ft. Gross	Heat of combustion: Btu per cu. ft. Net	Heat of combustion: Btu per lb Gross	Heat of combustion: Btu per lb Net	Cu. ft per cu. ft. of combustible: Required for combustion: O_2	N_2	Air	Flue products: CO_2	H_2O	N_2	Lbs. per lb. of combustible: Required for combustion: O_2	N_2	Air	Flue products: CO_2	H_2O	N_2
1	Carbon	C	.....	.....	.....	.....	.....	14,140†	14,140†	....	.....	....	....	...	.....	2.667	8.873	11.540	3.667	.....	8.873
2	Hydrogen	H_2	0.005327	187.723	0.06959	323.5	275.1	61,100	51,643	0.5	1.882	2.382	...	1.0	1.882	7.939	26.414	34.353	.....	8.939	26.414
3	Oxygen	O_2	0.08461	11.819	1.1053	.....	.....	.....	.....	....	.....	.....	...	...	.....	.....	.....	.....	.....	.....	.....
4	Nitrogen (atmos.)	N_2	0.07439*	13.443*	0.9718*	.....	.....	.....	.....	....	.....	.....	...	...	.....	.....	.....	.....	.....	.....	.....
5	Carbon monoxide	CO	0.07404	13.506	0.9672	323.5**	323.5	4,369	4,369	0.5	1.882	2.382	1.0	...	1.882	0.571	1.900	2.471	1.571	.....	1.900
6	Carbon dioxide	CO_2	0.1170	8.548	1.5282	.....	.....	.....	.....	....	.....	.....	...	...	.....	.....	.....	.....	.....	.....	.....
Paraffin series C_nH_{2n+2}																					
7	Methane	CH_4	0.04243	23.565	0.5543	1014.7‡	913.8	23,912	21,533	2.0	7.528	9.528	1.0	2.0	7.528	3.992	13.282	17.274	2.745	2.248	13.282
8	Ethane	C_2H_6	0.08029*	12.455*	1.04882*	1781	1631	22,215	20,312	3.5	13.175	16.675	2.0	3.0	13.175	3.728	12.404	16.132	2.929	1.799	12.404
9	Propane	C_3H_8	0.1196*	8.365*	1.5617*	2572	2371	21,564	19,834	5.0	18.821	23.821	3.0	4.0	18.821	3.631	12.081	15.712	2.996	1.635	12.081
10	Iso-butane	C_4H_{10}	0.1582*	6.321*	2.06654*	3251	2999	21,247	19,606	6.5	24.467	30.967	4.0	5.0	24.467	3.581	11.914	15.495	3.030	1.551	11.914
11	n-Butane	C_4H_{10}	0.1582*	6.321*	2.06654*	3353	3102	21,247	19,606	6.5	24.467	30.967	4.0	5.0	24.467	3.581	11.914	15.495	3.030	1.551	11.914
12	n-Pentane	C_5H_{12}	0.1904*	5.252*	2.4872*	3981	3679	20,908	19,322	8.0	30.114	38.114	5.0	6.0	30.114	3.551	11.815	15.366	3.052	1.499	11.815
13	n-Hexane	C_6H_{14}	0.2274*	4.398*	2.9704*	4667	4315	20,526	18,976	9.5	35.760	45.260	6.0	7.0	35.760	3.530	11.745	15.275	3.067	1.465	11.745
Olefin series C_nH_{2n}																					
14	Ethylene	C_2H_4	0.07456	13.412	0.9740	1631	1530	21,884	20,525	3.0	11.293	14.293	2.0	2.0	11.293	3.425	11.395	14.820	3.139	1.285	11.395
15	Propylene	C_3H_6	0.1110*	9.007*	1.4504*	2336	2185	21,042	19,683	4.5	16.939	21.439	3.0	3.0	16.939	3.425	11.395	14.820	3.139	1.285	11.395
16	Butylene	C_4H_8	0.1480*	6.756*	1.9336*	3135	2884	20,840	19,481	6.0	22.585	28.585	4.0	4.0	22.585	3.425	11.395	14.820	3.139	1.285	11.395
17	Acetylene	C_2H_2	0.06971	14.344	0.9107	1503	1453	21,572	20,840	2.5	9.411	11.911	2.0	1.0	9.411	3.075	10.231	13.306	3.383	0.692	10.231
Aromatic series C_nH_{2n-6}																					
18	Benzene	C_6H_6	0.2060*	4.852*	2.6920*	3741	3590	18,150	17,418	7.5	28.232	35.732	6.0	3.0	28.232	3.075	10.231	13.306	3.383	0.692	10.231
19	Toluene	C_7H_8	0.2431*	4.113*	3.1760*	4408	4206	18,129	17,301	9.0	33.878	32.878	7.0	4.0	33.878	3.128	10.407	13.535	3.346	0.783	10.407
20	Xylene	C_8H_{10}	.....	.....	.....	5155	.....	18,410	.....	10.5	39.524	50.024	8.0	5.0	39.524	3.168	10.540	13.708	3.318	0.849	10.540
21	Naphthalene	$C_{10}H_8$	.....	.....	.....	5859	.....	17,298	.....	12.0	45.170	57.170	10.0	4.0	45.170	2.999	9.978	12.977	3.436	0.563	9.978
Miscellaneous gases																					
22	Ammonia	NH_3	0.04563*	21.914*	0.5961	433	.....	9,598	.....	....	.....	.....	...	...	.....	.....	.....	.....	.....	.....	.....
23	Hydrogen sulfide	H_2S	0.09109*	10.979*	1.1898*	672	.....	7,479	.....	1.5	5.646	7.146	SO_2= 1.0	1.0	5.646	1.408	4.685	6.093	SO_2= 1.880	0.529	4.685
24	Sulfur dioxide	SO_2	0.1733	5.770	2.264	.....	.....	.....	.....	....	.....	.....	...	...	.....	.....	.....	.....	.....	.....	.....
25	Water vapor	H_2O	0.04758*	21.017*	0.6215*	.....	.....	.....	.....	....	.....	.....	...	...	.....	.....	.....	.....	.....	.....	.....
26	Air	....	0.07655	13.063	1.0000	.....	.....	.....	.....	....	.....	.....	...	...	.....	.....	.....	.....	.....	.....	.....

NOTES:

All gas volumes corrected to 60° F. and 30" Hg dry.

* Densities calculated from values given in grams per liter at 0° C. and 760 mm. in the International Critical Tables for the known deviations from the gas laws. Where the coefficient of expansion was not available, the assumed value was taken as 0.0037 per ° C. Compare this with 0.003662 which is the coefficient for a perfect gas. Where no densities were available the volume of the mol was taken as 22.4115 liters. The asterisk (*) denotes that either the density or the coefficient of expansion has been assumed. The heats of combustion have been obtained by reviewing the experimental and critical data available. The 1929 A.G.A. Chemical Committee examined and approved the selection for the Gas Chemists Handbook. As far as possible the net heat of combustion per lb is the base figure from which all others were calculated. The data, given in mean Btu per lb (1/180th of the heat per lb of water from 32° F to 212° F.) have been compiled largely from Bureau of Standards publications, Bulletins of the University of Illinois Engineering Experimental Station, International Critical Tables, etc.

† Carbon — Roth and Naesser, Z. für Elektrochemie 31:461 (1925). White and black diamonds.

‡ Methane — Research Paper 260, Bureau of Standards (January 1931) corrected. C_8H_{10}, $C_{10}H_8$, H_2S and NH_3 from 1929 A.G.A. Gas Chemists Handbook.

For precise calculations with gases saturated with water vapor, 1.73% of the Btu value must be deducted to correct for the presence of water vapor.

Gross heating values are calculated from the net by allowing for the heat of vaporization of water at 60° F., amounting to 50.3 Btu per cu ft of water vapor or 1057.8 Btu per lb.

** Rossini in Bureau of Standards Research Paper 260 finds the heat of combustion of carbon monoxide to be 321.7 Btu per cu ft. Although not adopted for this edition, there is reason to believe that Rossini's value is the most accurate now available.

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PHYSICAL CONSTANTS OF HYDROCARBONS AND OTHER COMPOUNDS ASSOCIATED WITH NATURAL GAS

	Methane	Ethane	Propane	iso-butane	n-butane	iso-pentane	n-pentane	n-hexane	n-heptane	Carbon dioxide	Nitrogen	Oxygen	Air	Hydrogen sulphide	Water
Atomic formula	CH_4	C_2H_6	C_3H_8	C_4H_{10}	C_4H_{10}	C_5H_{12}	C_5H_{12}	C_6H_1	C_7H_{16}	CO_2	N_2	O_2	.....	H_2S	H_2O
Molecular weight	16.042	30.068	44.094	58.120	58.120	72.146	72.146	86.172	100.198	44.01	28.016	32.000	28.966	34.076	18.016
Boiling point—760 mm °F	−258.5	−128.2	−43.8	+10.0	+31.1	+82.3	+97.0	+155.7	+209.1	−109.3	−320.4	−297.4	.....	−76.5	212
°C	−161.4	−89.0	−42.1	−12.2	−0.5	+27.9	+36.1	+68.7	+98.4	−78.5	−195.8	−183.0	.....	−60.3	100
Melting point—760 mm. °F	−296.5	−297.8	−305.8	−229.0	−218.2	−257.1	−201.5	−139.9	−131.4	*	−345.6	−361.1	.....	−121.9	+32
°C	−182.5	−183.2	−187.7	−145.0	−139.0	−160.6	−129.7	−95.5	−90.8	*	−209.8	−218.4	.....	−85.5	0.0
Critical temperature °R	343.1	549.7	665.8	732.8	765.2	829.6	846.5	914.2	972.2	547.6	226.8	277.7	238.3	672.3	1165.0
°K	190.6	305.4	369.9	407.1	425.1	460.9	470.3	507.9	540.1	304.2	126.0	154.3	132.4	373.5	647.2
°F	−116.5	+90.1	206.2	273.2	305.6	370.0	387.0	454.6	512.6	88.0	−232.8	−181.8	−221.3	+212.7	+705.4
°C	−82.5	+32.3	96.8	134.0	152.0	187.8	197.2	234.8	267.0	31.1	−147.1	−118.8	−140.7	+100.4	+374.1
Critical pressure															
Atmospheres	45.8	48.2	42.0	35.2	37.5	32.8	33.0	29.5	27.0	73.0	33.5	49.7	37.2	88.9	218.2
Lb. per sq. in. abs.	673	708	617	517	551	482	485	434	397	1073	492	730	547	1306	3206.2
Critical volume															
Mi. per gal. mol.	99.0	148.0	195.0	249.0	258.0	307.6	310.9	367.2	427.0	95.6	90.1	74.4	93.4	.....	56.6
Cu. ft. per lb. mol.	1.586	2.371	3.123	3.990	4.130	4.930	4.98	5.88	6.84	1.532	1.443	1.192	1.496	.....	0.906
Critical density lb. per gal.	1.351	1.695	1.888	1.946	1.891	1.955	1.935	1.958	1.957	3.839	2.596	3.589	2.588	.....	2.658
Liquid density data															
Specific gravity															
60°/60°F	0.3	0.4	0.509	0.564	0.584	0.625	0.631	0.664	0.688	.....	.....	.....	.....	0.79	1.000
°A.P.I. at 60°F.	340.0	222.0	146.5	119.4	110.8	94.9	92.7	81.6	74.2	.....	.....	.....	.....	47.6	10.0
Density, lb. per gal. at 60°F (wt. in air)	2.5	3.3	4.23	4.69	4.86	5.20	5.25	5.53	5.73	.....	.....	.....	.....	6.58	8.327
Vapor density data (760 mm., 60°F															
Specific gravity (perfect gas) (air = 1.00)	0.554	1.038	1.522	2.006	2.006	2.491	2.491	2.975	3.459	1.519	0.967	1.105	1.000	1.176	0.622
Density (perfect gas)															
Cu. ft. per lb.**	23.66	12.62	8.61	6.53	6.53	5.26	5.26	4.40	3.79	8.62	13.54	11.86	13.10	11.14	21.06
Lb. per 1000 cu. ft.***	42.27	79.23	116.2	153.2	153.2	190.1	190.1	227.1	264.0	116.0	73.83	84.32	76.33	89.80	47.48
Cu. ft. vapor per gal. liquid (perfect gas)**	59.17	42.09	36.52	30.70	31.79	27.41	27.67	24.38	21.72	.....	.....	.....	.....	73.35	175.62
Gal. liquid per 1000 cu. ft. vap. (perfect gas)***	16.90	23.76	27.38	32.57	31.45	36.48	36.14	41.02	46.03	.....	.....	.....	.....	13.63	5.69
Ratio gas volume per liquid volume (perfect gas)	442.6	314.8	273.2	229.7	237.8	205.0	207.0	182.4	162.5	.....	.....	.....	.....	548.7	1313.7
Deviation factor—(760 mm. 60°F)	1.0020	1.008	1.016	1.030	1.032	1.045	1.048	1.066	1.087	1.0058	1.00030	1.00075	1.00039	1.011	1.0012
															13.25 mm.
100°F.	1.0015	1.007	1.013	1.025	1.027	1.040	1.043	1.056	1.071	1.0047	1.00012	1.00052	1.00020	.....	1.0026
															49.1 mm
Gross heat of combustion															
B.t.u. per lb. vapor	23,916	22,350	21,692	21,288	21,338	21,058	21,121	20,970	20,859	.....	.....	.....	.....	7,479	.....
B.t.u. per cu. ft. (perfect gas) 30-in.—60°F (dry)****	1013	1775	2526	3268	3276	4012	4025	4773	5521	.....	.....	.....	.....	673	.....
Specific heat B.t.u. per lb. (760 mm., 60°F.)															
Cp	0.530	0.415	0.376	0.357	0.357	.....	0.347	0.339	0.335	0.199	0.248	0.218	0.241	0.254	0.458
Cv	0.405	0.346	0.324	0.312	0.312	0.309	0.309	0.305	0.302	0.153	0.176	0.155	0.171	0.192	0.343
Cp/Cv	1.309	1.198	1.161	1.144	1.144	1.121	1.121	1.113	1.109	1.304	1.404	1.401	1.410	1.32	1.335
Cp Liq.	.....	.....	.....	.55 at 32	.55 at 32	.53	.64	.536	.522	.....	.....	.....	.....	.....	1.000
Heat of fusion B.t.u. per lb.—760 mm.	25.2	40.9	34.4	.....	32.4	30.4	49.9	65.0	59.6	81.5	11.0	5.9	.....	30.0	143.4
Heat of vaporization at boiling point B.t.u. per lb.—760 mm	249	210	183	157	165	150	151	143	137	.....	.....	.....	.....	236	971
Vapor pressure at 100°F., lb. per sq. in. abs.	.....	.....	189.5	73.5	52.0	20.3	15.5	5.0	1.63	.....	.....	.....	.....	554.6	0.949
Octane No. Motor Method. A S T M D 357-37T	100+	100+	99.5	97.0	90.5	88.7	69.3	59.0	0.0	.....	.....	.....	.....	.....	.....

*Sublimes.
**To convert to a basis of 14.73 lb. per sq. in. or 30 in. Hg multiply by 0.99769.
***To convert to a basis of 14.73 lb. per sq. in. or 30 in. Hg multiply by 1.00232.
****To convert to a basis of water saturation at 60°F multiply by 0.9825.

Note: Except where otherwise indicated, values are expressed on an "Actual" gas basis.

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TANK FORMULAS

The following formulas have been selected to facilitate the rapid calculation of capacities of various types of storage tanks in gallons and barrels.

Uniform Notations:

B — Capacity of each dished head in United States gallons.

B_2 — Total capacity of both dished heads in United States gallons.

C_B — Total capacity of tank in barrels (of 42 United States gallons).

C_G — Total capacity of tank in United States gallons.

C_{GF} — Capacity of cylindrical portion of tank in United States gallons per foot length. (Flat heads.)

D — Inside diameter of tank in feet.

G — Liquid contents of partially filled tank in United States gallons.

L — Length of cylindrical portion of tank in feet.

b — Dish of head, bead line to inside of plate (height of arc) in inches.

d — Inside diameter of tank in inches.

h — Depth or height of liquid in tank in inches.

l — Length of cylindrical portion of tank in inches.

r — Radius of dished head (where different from tank diameter) in inches.

Capacity of Vertical Cylindrical Tanks with Flat Heads

R — Inside radius of tank in feet.

H — Height of liquid in feet.

Capacity in United States gallons, per foot depth

$C_{gf} = 23.501\ R^2$.

Total capacity in United States gallons

$C_g = 23.501\ R^2H$.

Total capacity in barrels (of 42 United States gallons)

$C_b = 0.56\ R^2H$.

Capacity of Horizontal Cylindrical Tanks with Flat Heads

Total capacity in United States gallons

$C_g = 0.0034\ d^2l$.

Total capacity in barrels (of 42 United States gallons)

$C_b = 0.14\ D^2L$.

Capacity of Horizontal Cylindrical Tanks with Dished Heads

(where radius of dished head equals diameter of tank)

Total capacity in United States gallons

$C_g = 0.0034\ d^2l + 0.0004664\ d^3$.

Total capacity in United States gallons

$C_g = 5.875\ D^2L + 0.806\ D^3$.

Total capacity in barrels (of 42 United States gallons)

$C_b = 0.14\ D^2L + 0.019\ D^3$.

Capacity of Dished Head of any Radius

Capacity of each dished head in United States gallons

$B = 0.0045333\ b^2\ (3r - b)$.

Capacity of Spherical Tanks

Total capacity in United States gallons

$C_g = 0.0022666\ d^3$.

Total capacity in United States gallons

$C_g = 3.9168\ D^3$.

Total capacity in barrels (of 42 United States gallons)

$C_b = 0.093257\ D^3$.

Liquid Contents of partially filled Tanks

Horizontal Cylindrical Tanks with Flat Heads:

Liquid contents in United States gallons.

$$G = \frac{1}{231}\left[0.004363\ d^2\ \mathrm{Cos}^{-1}\frac{d-2h}{d} - \frac{d-2h}{2}\sqrt{h(d-h)}\right].$$

The notation $\mathrm{Cos}^{-1}\ \frac{d-2h}{d}$ (read inverse cosine of $\frac{d-2h}{d}$, or arc cosine $\frac{d-2h}{d}$) means the angle (in degrees) whose cosine is equal to $\frac{d-2h}{d}$.

The use of this inverse function can best be illustrated by an example:

Find the number of gallons contained in a horizontal cylindrical tank with flat heads, if the tank inside diameter is 100 inches, the length 50 inches, and the tank is filled with liquid to a depth of 10 inches. Substituting in the above formula,

$$G = \frac{50}{231}\left[0.004363(100)^2\mathrm{Cos}^{-1}\ \frac{100-20}{100} - \frac{100-20}{2}\sqrt{10(100-10)}\right],$$

$$G = 0.21645\ [\,43.63\ \mathrm{Cos}^{-1}\ 0.80 - 40\sqrt{900}\,].$$

But, as stated above, Cos^{-1} 0.80 means "the angle of which the cosine is 0.80." From a table of natural cosines the angle is found to be 36° 52′ or 36.87°. Substituting this value for Cos^{-1} 0.80 we have,

$G = 0.21645\ (43.63 \times 36.87 - 1200)$,

$G = 0.21645 \times 408.6$,

$G = 88.45$ gallons.

Note: In calculating liquid contents of partially filled tanks, use formula for tanks up to half full. For tanks over half full, calculate capacity of unfilled portion and subtract from capacity of full tank.

Spherical Tanks:

G = Liquid contents in United States gallons

$= 0.0022666h^2(3d - 2h)$.

VAPOR PRESSURES OF PROPANE, BUTANE AND ISOBUTANE

Temp. Deg. F.	Propane		Butane		Isobutane		Temp. Deg. F.
	Pressure—lbs. per sq. in						
	Absolute	Gauge	Absolute	Gauge	Absolute	Gauge	
—75	6.37	*17.0					—75
—70	7.37	*14.9					—70
—65	8.48	*12.7					—65
—60	9.72	*10.1					—60
—55	11.1	* 7.3					—55
—50	12.6	* 4.3					—50
—45	14.4	* 0.6					—45
—40	16.2	1.5					—40
—35	18.1	3.4					—35
—30	20.3	5.6					—30
—25	22.7	8.0					—25
—20	25.4	10.7			7.50	*14.6	—20
—15	28.3	13.6			8.30	*13.0	—15
—10	31.4	16.7			9.28	*11.0	—10
— 5	34.7	20.0			10.4	* 8.8	— 5
0	38.2	23.5	7.3	*15.0	11.6	* 6.3	0
5	41.9	27.2	8.2	*13.2	13.1	* 3.3	5
10	46.0	31.3	9.2	*11.1	14.6	* 0.2	10
15	50.6	35.9	10.4	* 8.8	16.3	1.6	15
20	55.5	40.8	11.6	* 6.3	18.2	3.5	20
25	60.9	46.2	13.0	* 3.6	20.2	5.5	25
30	66.3	51.6	14.4	* 0.6	22.3	7.6	30
35	72.0	57.3	16.0	1.3	24.6	9.9	35
40	78.0	63.3	17.7	3.0	26.9	12.2	40
45	84.6	69.9	19.6	4.9	29.5	14.8	45
50	91.8	77.1	21.6	6.9	32.5	17.8	50
55	99.3	84.6	23.8	9.1	35.5	20.8	55
60	107.1	92.4	26.3	11.6	38.7	24.0	60
65	115.4	100.7	28.9	14.2	42.2	27.5	65
70	124.0	109.3	31.6	16.9	45.8	31.1	70
75	133.2	118.5	34.5	19.8	49.7	35.0	75
80	142.8	128.1	37.6	22.9	53.9	39.2	80
85	153.1	138.4	40.9	26.2	58.6	43.9	85
90	164.0	149.0	44.5	29.8	63.3	48.6	90
95	175.0	160.0	48.2	33.5	68.4	53.7	95
100	187.0	172.0	52.2	37.5	73.7	59.0	100
105	200.0	185.0	56.4	41.7	79.3	64.6	105
110	212.0	197.0	60.8	46.1	85.1	70.4	110
115	226.0	211.0	65.6	50.9	91.4	76.7	115
120	240.0	225.0	70.8	56.1	98.0	83.3	120
125	254.0	239.0	76.0	61.3	104.8	90.1	125
130	272.0	257.3	81.4	66.7	112.0	97.3	130
135	288.0	273.3	87.0	72.3	119.3	104.6	135
140	305.0	290.3	92.6	77.9	126.8	112.1	140
145			100.0	85.3	136.0	121.3	145
150			108.0	93.7	145.0	130.3	150
155			115.0	100.3	155.0	140.3	155
160			122.0	107.3	165.0	150.3	160
165			130.0	115.3	175.0	160.3	165
170			140.0	125.3	186.0	171.3	170
175			150.0	135.3	198.0	183.0	175
180			160.0	145.3	210.0	195.3	180

*Inches of mercury below one standard atmosphere (29.92 in.).

Dana, Jenkins, Burdick and Timm, Refrigerating Engineering, June 1926.

U.G.I. Equipment

U.G.I. Cyclic Catalytic Reforming Process*
Gas Main and Pipeline Construction
High Btu Oil Gas Apparatus
General Gas Plant Extensions
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Carburetted and Blue Water Gas Plants
Mechanical Generators and Chargers
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The process has been in commerical operation for seven years and there are now 16 installations in operation and 2 under construction, in 11 plants. The process is an adaptation of the efficient cyclic principle used for years in the production of blue and carburetted water gas. The operating requirements are simple.

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CONSTRUCTION-INSPECTION SERVICES FOR GAS MAIN AND PIPELINE CONSTRUCTION

United Engineers' construction-inspection services for pipelines and distribution mains can supplement your distribution department's forces during the most active part of your construction program. It can operate as an adjunct to your inspection and supervision or to handle definite portions of the construction.

Well-qualified men of long experience are provided, who, in addition to being technically equipped for their work, are accustomed to handling and taking part in large construction operations. They are backed by a responsible organization with a wide construction background.

Our services assist in bringing to your organization the latest techniques and methods of construction and give you assurance that the work will be carried out in accordance with your specifications and your high standards of security and safety — and at reasonable cost.

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Through the years, United Engineers has built up large, well-organized and experienced forces for handling extensions to general gas plant facilities, including gas handling and treating equipment, compressors, boilers, buildings and foundations, and additions and reinforcements to plant electric and mechanical services.

No matter what your project we invite you to share our experience and facilities as designers, constructors and consulting engineers.

*Patents Pending

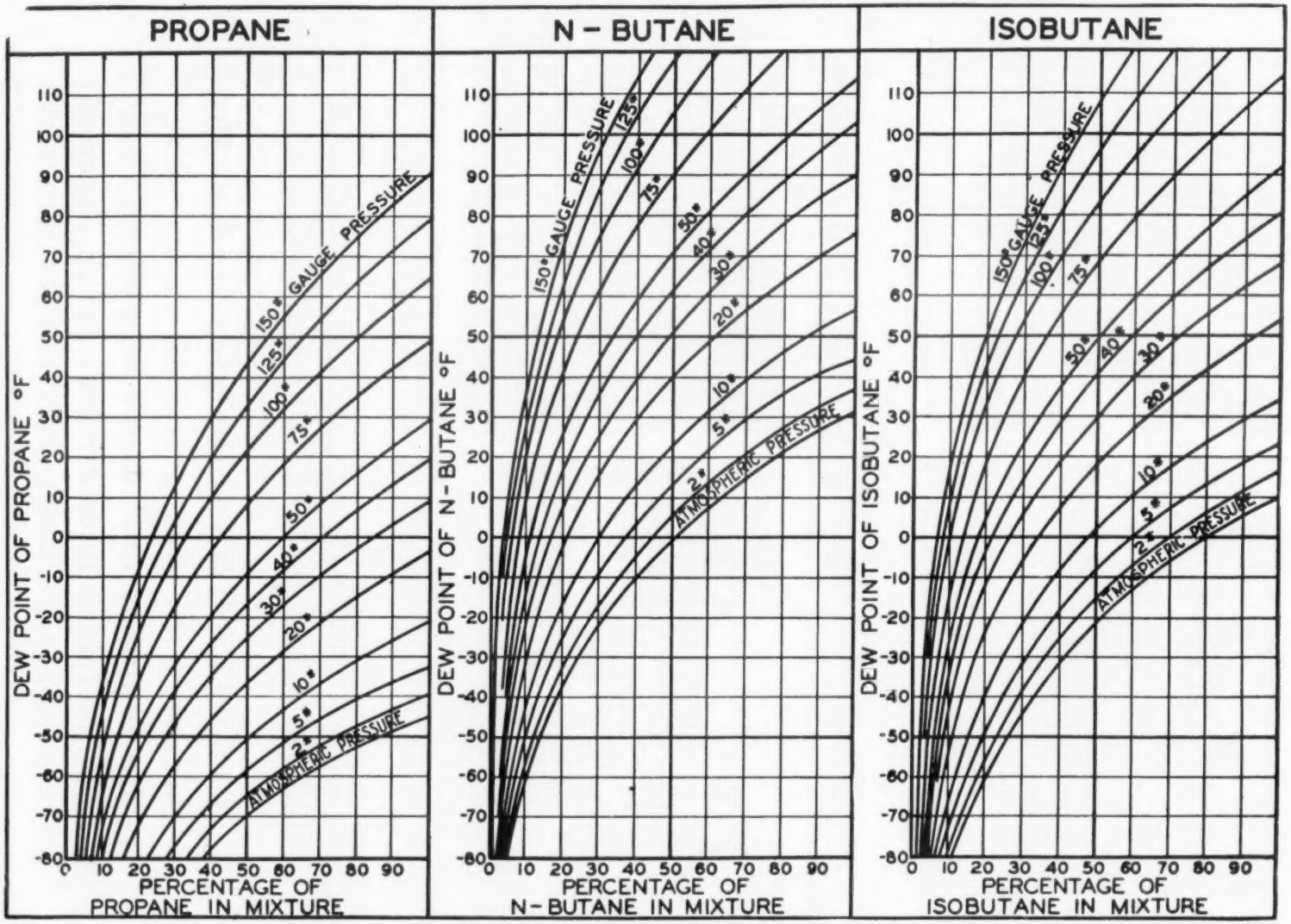
UNITED ENGINEERS

& Constructors Inc

U.E.&C. (Canada) Ltd.

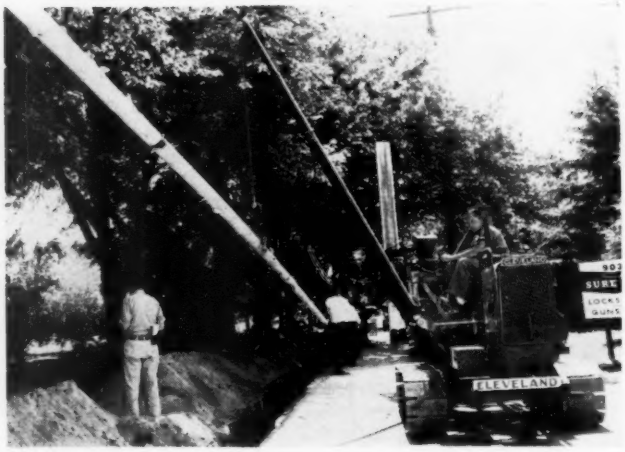
New York 17 • PHILADELPHIA 5 • Chicago 2

DEW POINTS OF PROPANE, NORMAL BUTANE AND ISOBUTANE, CARBURETTED WITH AIR

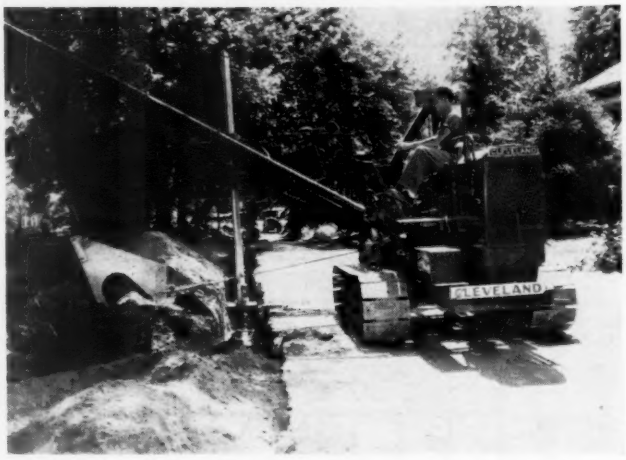


Copyright, page 38, 3rd edition Handbook Butane-Propane Gases.

Trenching • Pipelaying



Backfilling • Tamping



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CLEVELANDS – the standard of the industry for more than 30 years – have the features that count in getting these gas jobs done better, faster, safer, cheaper.

Check your job requirements now with your Cleveland distributor.

Good Everywhere

THE CLEVELAND TRENCHER COMPANY

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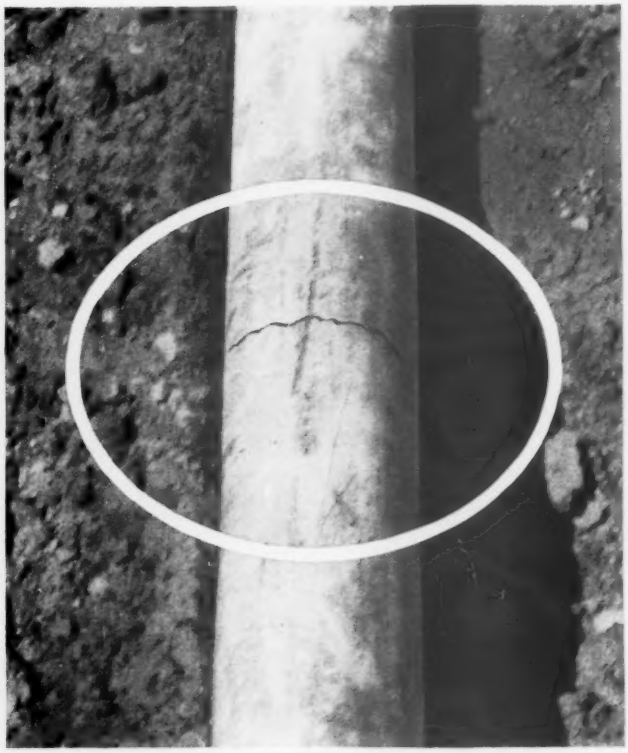
AVERAGE PROPERTIES OF LIQUEFIED PETROLEUM GAS PRODUCTS

	Commercial propane	Industrial propane	Commercial butane
Vapor pressure lbs./sq. in. gauge			
at 70° F.	124	122	31
at 100° F.	192	190	59
at 105° F.	206	204	65
at 130° F.	286	282	97
Specific gravity of liquid (60°/60° F.)	0.509	0.511	0.582
Initial boiling point at 14.7 lbs./sq. in. abs., °F	—51	—51	15
Weight per gallon of liquid at 60° F., lbs	4.24	4.26	4.84
Dew point at 14.7 lbs./sq. in. abs., °F	—46	—45	24
Specific heat of liquid, btu/lb./°F. at 60° F.	0.588	0.587	0.549
Cu. ft. of gas at 60° F., 30″ hg. per gallon of liquid at 60° F.	36.28	36.18	31.46
Specific volume of gas, cu. ft./lb. at 60° F., 30″ hg	8.55	8.50	6.50
Specific heat of gas, btu/lb./°F. at 60° F. (Cp)	0.404	0.401	0.382
Specific gravity of gas (Air = 1) at 60° F., 30″ hg	1.52	1.53	2.01
Ignition temperature in air, °F	920–1020	920–1020	900–1000
Maximum flame temperature in air, °F	3595	3600	3615
Per cent gas in air for maximum flame temperature, %	4.2–4.5	4.2–4.4	3.3–3.4
Maximum rate of flame propagation in 25 mm. tube:			
Cms. per second	84.9	85.9	87.1
Inches per second	33.4	33.8	34.3
Limits of inflammability in air, gas per cent in gas-air mixture:			
At lower limit, %	2.4	2.4	1.9
At maximum rate of flame propagation, %	4.7–5.0	4.7–4.9	3.7–3.9
At upper limit, %	9.6	9.6	8.6
Required for complete combustion:			
Cu. ft. O_2/cu. ft. gas	4.9	4.9	6.3
Cu. ft. air/cu. ft. gas	23.4	23.4	30.0
Lbs. O_2/lb. gas	3.60	3.59	3.54
Lbs. air/lb. gas	15.58	15.52	15.3
Products of complete combustion:			
Cu. ft. CO_2/cu. ft. gas	3.0	3.0	3.9
Cu. ft. H_2O/cu. ft. gas	3.8	3.8	4.6
Cu. ft. N_2/cu. ft. gas	18.5	18.5	23.7
Lbs. CO_2/lb. gas	3.0	3.0	3.1
Lbs. H_2O/lb. gas	1.6	1.5	1.5
Lbs. N_2/lb. gas	12.0	11.9	11.8
Ultimate CO_2, % by volume	13.9	13.9	14.1
Latent heat of vaporization at boiling point:			
Btu per pound	185	184	167
Btu per gallon	785	784	808
Total heating values (after vaporization):			
Btu per cubic foot	2522	2537	3261
Btu per pound	21560	21570	21180
Btu per gallon	91500	91800	102600

Phillips Petroleum Company, with permission.

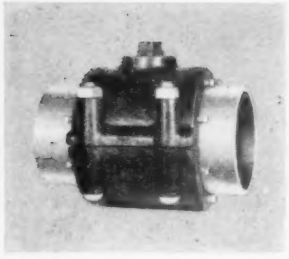
in 10 minutes...

PIPE BREAK TO PERMANENT REPAIR

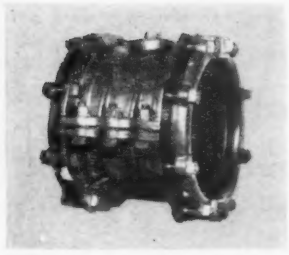


...ORDER NOW

FOR WINTER BREAKS!



Style 80—Ready-Pack Sleeve. Light weight, low cost. Insures gastight repairs, even on off-size pipe. Completely encloses the break. Fast, one-man repair on cast iron pipe from 3" to 8" diameter.



Style 57C—Cast Split Sleeve for longer breaks or splits in straight run of pipe. Quickly installed on cast iron pipe 2" to 12" diameter. Two or more sleeves can be joined to cover pipe breaks longer than 8".

Be ready to make quick, permanent, leakproof repairs if pipe breaks occur this winter. Order your Dresser Sleeve and Clamp assemblies now.

Each Dresser Style 80 Repair Sleeve comes completely assembled ready for installation and equipped with a handle for easy carrying to the trouble spot. Regardless of weather or location, one man using just a wrench can make a permanent repair on cast iron pipe in 5 to 10 minutes.

Here is "packaged repair" . . . a fast, modern technique insuring that pipe lines go back into full service immediately . . . another Dresser product designed to help you protect your investment and maintain the good will of your customers.

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VAPORIZATION OF LIQUID IN PROPANE TANKS

Many times the question arises, especially on peak shaving installations using propane: Is it necessary to turn on the vaporizers?

For comparatively short-time peak shaving it is possible to obtain sufficient vapor from the storage tank itself without passing liquid propane through the vaporizer.

It is a well-known fact that the vapor pressure of a gas bears a direct relationship to the temperature and that the latent heat of vaporization is the amount of heat required to convert a liquid to a gas (also known as boiling point) at given pressure and temperature conditions; and further:

"The rate of heat transfer has been set at 2 Btu per hour per degrees temperature differential per sq. ft. of tank area in contact with the liquid."

Knowing these basic gas laws, we can evolve a formula to determine the amount of liquid propane vaporized in a standard storage tank in one hour.

$$\frac{2\ \text{Btu} \times (T_1 - T_2) \times \text{wetted area in sq ft}}{\text{LH per gal}} = \text{Gal/hr}$$

T_1 = Outside air temperature in degrees F

T_2 = Ultimate temperature in degrees F of propane liquid at minimum required pressure condition

LH: per gal = Latent Heat of vaporization (in Btu's) to vaporize one gallon of propane at T_2

As an example, let us assume that a 30,000 (wc) tank is half full of propane (wetted area = 1014 sq. ft.) and the outside air temperature is 80 F and the required vapor pressure can be as low as 10 psi gauge. How many gallons per hour is available due to the vaporization of liquid in storage tank?

Referring to standard table of thermodynamic properties of propane; temperature at 10 psi ga is —20 F; and the latent heat of vaporization is 750 Btu per gal.

From the above formula —

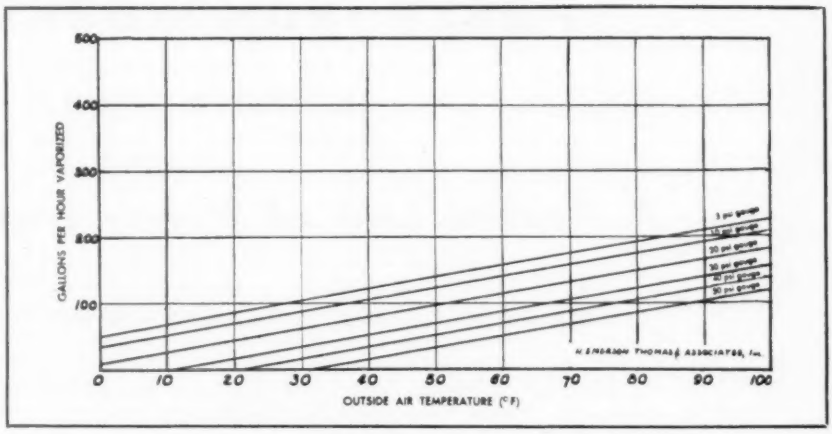
$$\frac{2\ \text{Btu} \times (80°\text{F} - (20°\text{F}) \times 1014\ \text{sq ft}}{750\ \text{Btu per gal}} = 271\ \text{gal}$$

With the above conditions, we therefore can vaporize 271 gallons per hour without recourse to a vaporizer.

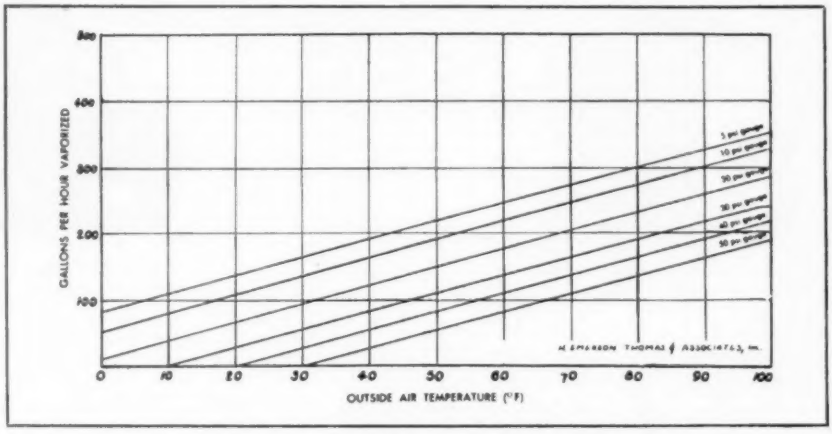
If this draw is maintained over a long period of time on a humid day, the surface of the tank in contact with the liquid will become frosted due to the refrigeration action of the liquid vaporized and the effective temperature differential will be substantially reduced. But in this discussion we are considering only comparatively short usages so as to obtain maximum vaporization.

Using the basic formula, graphs have been plotted which give available gallons per hour vaporized at various outside temperatures and pressure requirements of vapor and at varying filling heights in a 30,000 gallon (wc) tank containing commercial grade propane.

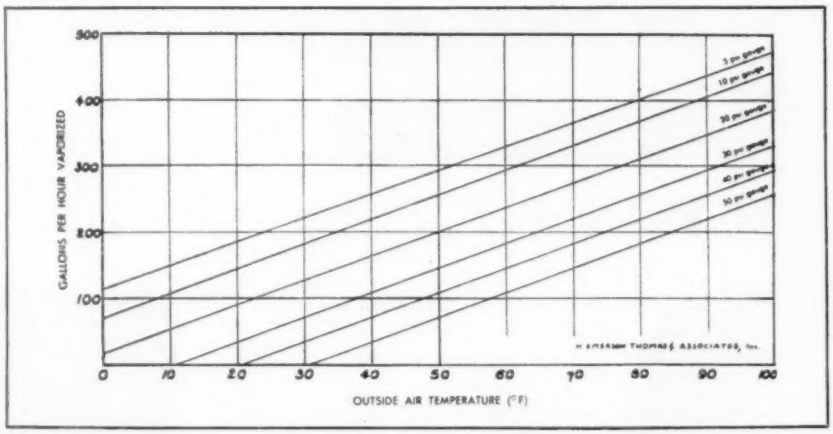
Referring to the graphs it is possible to decide when the vaporizer equipment will be required to obtain the necessary gas load.



Vaporization in 30,000 gallon tank, ¼ full—662 sq ft.



Vaporization in 30,000 gallon tank, ½ full—1014 sq ft.



Vaporization in 30,000 gallon tank, ¾ full—1365 sq ft.

Art E. Wastie, chief engineer, H. Emerson Thomas and Associates, Westfield, N. J.

POSEY IRON WORKS, INC.

STEEL PLATE DIVISION

LANCASTER – PENNA.

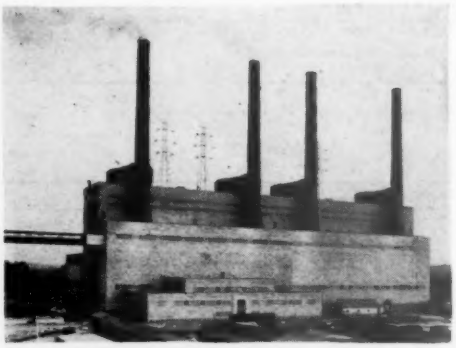
NEW YORK OFFICE • GRAYBAR BLDG.

A Partial List of Posey Iron Products

Autoclaves • Barges • Bins • Butane-Propane Tanks • Condensers • Digesters • Dredge Hulls and Pipe • Dryer Shells • Elevated Tanks (Steel and Alloy Steel) • Fabricated Steel Plate • Gas Holders • Kilns • Pressure Vessels • Retorts • Stacks • Stand Pipes • Stills • Storage Tanks (Steel and Alloy Steel) • Welded and Riveted Pipe • Wrought Iron, Steel and Alloy Steel Pipe.

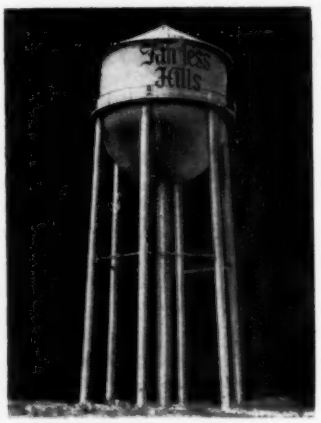
Posey Iron builds high and low pressure vessels for both liquids and gas.

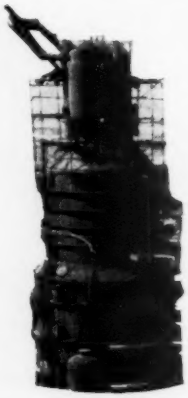
Posey Iron stainless clad digester is shown mounted on truck enroute to user. 13' O. D. x 40' long.



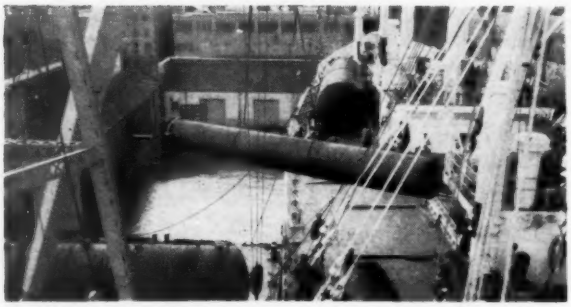
These four stacks by Posey Iron measure 23' diameter by 192'-6" high.

250,000 gallon water tank stands 105 feet above ground. Supplied with water from wells 65 to 75 feet underground.





Vacuum tower for crude distilling fabricated throughout by Posey Iron Works.



Horizontal storage tanks being loaded aboard freighter for export. Many Posey Iron installations are overseas.

DIVISIONS: BRICK MACHINERY • FOUNDRY • HEATING • IROQUOIS • SHIPBUILDING • STEEL PLATE

CALCULATING EXPLOSIVE LIMITS OF GAS MIXTURES IN AIR

Coward and his co-workers have arranged the Le Chatelier formula in the following form for calculating the limits in air of any mixture of combustible gases to which it is applicable:

$$L = \frac{100}{\frac{P_1}{N_1} + \frac{P_2}{N_2} + \frac{P_3}{N_3} + \text{—}}$$

Where P_1, P_2 and P_3 are the proportions of each combustible gas present in the original mixture, free from air and inert gases so that

$$P_1 + P_2 + P_3 + \text{—} = 100$$

and N_1, N_2, N_3 are the limits in air for each gas separately, no inest gases being psesent.

EXPLOSIVE LIMITS OF SELECTED INDUSTRIAL GASES IN AIR

Kind of Gas	Heating value B.t.u./ Cu. Ft.	Composition—% by Volume								Explosive Limits	
		CO_1	Ill.	O_2	CO	H_2	CH_1	C_1H_6	N_2	Lower	Upper
Blue.....	310	6.2	0.0	0.3	39.2	49.0	2.3		3.0	6.9	69.5
	308	1.9	0.0	0.3	45.0	47.5	1.2		4.1	6.1	67.4
Carburetted..	509	4.6	7.3	0.3	36.0	37.0	9.6		5.2	6.4	37.7
Blue.....	538	3.9	8.2	0.7	32.4	33.7	13.1		8.0	6.8	37.3
	541	5.7	10.2	0.7	26.1	28.3	8.1	1.9	19.0	7.3	31.6
Coal.....	549	2.4	2.7	0.4	9.7	44.9	28.9		11.0	5.6	30.8
		1.6	3.1	1.2	8.5	50.3	26.0		9.3	5.8	29.0
Coke oven...	631	1.9	3.9	0.4	6.3	54.4	31.5		1.6	5.0	28.4
	540	2.5	3.4	0.8	11.1	47.9	24.2		10.1	5.3	30.0
	547	2.3	4.0	1.5	7.8	46.8	24.6	1.0	12.0	6.0	28.4
"Mixed".....	540	2.5	3.2	0.5	10.5	47.0	25.8		10.5	5.6	31.7
	540	3.8	5.7	1.3	22.4	38.5	18.1		10.2	6.3	34.0
	540	3.1	8.1	0.8	21.5	33.7	15.0	1.0	16.8	6.8	30.8
Producer.....	136	6.2	0.0	0.0	27.3	12.4	0.7		53.4	20.7	73.7
	118	5.4	0.0	0.0	26.6	9.3	0.4		58.3	18.6	*
Natural.....										4.8	13.5

S. S. Tomkins.

GAS IGNITION TEMPERATURES AND EXPLOSIVE LIMITS IN AIR

Gas or vapor	Ignition temperature °F	Explosive limits: Lower limit per cent by volume	Explosive limits: Upper limit per cent by volume
Carbon monoxide.....	1204	12.5	74.0
Hydrogen.....	1085	4.1	74.2
Methane.....	999	5.3	14.0
Ethane.....	950	3.2	12.5
Propane.....	871	2.37	9.5
n-Butane.....	806	1.6	8.5
iso-Butane.....	1010	1.9	8.5
Pentane.....	588	1.45	7.5
Hexane.....	500	1.2	6.9
Ethylene.....	842	2.75	28.6
Propylene.....	927	2.0	11.1
Benzene.....	1000	1.5	8.0
Toluene.....	1026	1.27	7.0
Xylene.....	900	1.0	5.3
Acetylene.....	581*	2.5	80.0
Naphthalene.....	1038	0.9	
Ammonia.....	1204	16.0	25.0
Hydrogen sulphide.....	500	4.3	46.0

National Fire Protection Association excerpt from Bureau of Mines Report of Investigations 3567.

SAFE END-POINTS IN PURGING OPERATIONS INVOLVING VARIOUS COMBUSTIBLE AND INERT GASES

Combustible gas or vapor	Inert gas	Safe end point—per cent by volume: Purging from air to gas maximum permissible oxygen content of atmosphere in container	Safe end point—per cent by volume: Purging from gas to air maximum permissible combustible gas content of atmosphere in container
Mixed gas.....	Nitrogen.....	8.6	11.0
Carburetted blue gas.....	Nitrogen.....	8.0	11.8
Coal gas.....	Nitrogen.....	9.0	10.0
Benzol vapor.....	Nitrogen.....	11.6	4.8
Hydrogen.....	Carbon dioxide.....	8.1	8.9
	Nitrogen.....	5.1	5.7
Carbon monoxide.....	Carbon dioxide.....	9.8	31.5
	Nitrogen.....	6.6	19.5
Methane.....	Carbon dioxide.....	15.7	22.6
	Nitrogen.....	12.8	14.0
Ethane.....	Carbon dioxide.....	14.0	11.7
	Nitrogen.....	11.4	7.2
Propane.....	Carbon dioxide.....	14.9	10.8
	Nitrogen.....	11.9	6.4
Butane.....	Carbon dioxide.....	15.0	9.2
	Nitrogen.....	12.4	5.6
Ethylene.....	Carbon dioxide.....	12.2	10.0
	Nitrogen.....	10.3	6.3

S. S. Tomkins.

RAPID SURVEY METHOD OF GAS REQUIREMENTS AND COSTS

In many of its phases, the selling of gas heat is very much like other specialty selling where the cost of the item or of the service to be furnished depends on the particular conditions surrounding the individual prospect.

The estimate of annual operating cost for one prospect may figure only $50.00, whereas that for another would be $500.00. When the one in the $500.00 class first makes inquiry about gas heat, his interest may be based on thinking in terms of $50.00. Likewise, the one who is in the $50.00 class may not have exhibited any interest, because he was thinking in terms of $500.00.

A method, therefore, whereby the salesman in the field can figure the estimate with reasonable accuracy and in just a few minutes time, is of great assistance in qualifying prospects. Such a method can be made sufficiently accurate to justify the salesman in attempting to close the order on the basis of the rapid survey method. If successful, then before the installation is made, his engineering department, if it so desires, can make a more elaborate survey and estimate. This can be done as if it is merely a part of the usual installation routine, so that the customer's confidence in the salesman is not affected in any way. Should this detailed survey show any glaring discrepancies, the matter can be taken up with the customer in advance of installation, so that no one will be unfavorably affected.

To show how such a rapid survey can be developed, the starting point is the formula used by heating engineers in figuring the seasonal operating cost to take care of any given area of wall, ceiling or floor.

FORMULA

$$\frac{\text{(Heat loss in Btu per Hour)}}{\text{Area} \times \text{Heat Transfer Coefficient} \times \text{Temp. Rise} \times \text{Hrs. Heated} \times \text{Degree Days} \times \text{Gas Rate in Cts. Per M Cu Ft}}{\text{Temperature Rise} \times \text{Btu Heat Content} \times \text{Efficiency} \times 1000 \times 100} = \text{Season's Operating Cost in Dollars for that Area}$$

While there are many factors in the long formula, examination will show that for any certain type of construction practically all of them are constant for any given territory. The coefficient of any certain material is always the same — the temperature rise is nearly always figured at 70 degrees — the temperature differential between basement and hour interior 20 degrees — and between interior and attic 35 degrees — the number of hours per day is always 24 — the number of degree days for any given territory is regarded as a constant — the gas rate and the Btu content are constant for a territory. While the efficiency factor may vary slightly with different types of equipment, an average efficiency of 75 per cent can be used for reasonably accurate results. This means that all of the factors in that long formula can be condensed for any territory into one single factor for each type of construction. Then it is simply a case of multiplying the given area by one factor instead of working out the entire formula shown above.

Another point of simplification is to measure the house as a whole rather than to measure the individual rooms. It is simple for the salesman to compute the volume by measuring the width, height, and depth of the house. Naturally, if the prospect states that certain rooms have not been heating satisfactorily with the old furnace equipment, then individual rooms should be measured and duct work or radiation checked. Just as in the case of figuring the heat loss through the walls, ceiling, or floor, the volume can be multiplied by a single constant to determine the seasonal operating cost for offsetting loss by infiltration.

With the above thought in mind, a single factor, which for purposes of clarity in explaining is called factor "F", has been worked out for the most commonly encountered types of construction. To convert this factor "F" into the correct constant for any territory, it is only necessary to multiply it by a certain multiplier, designated as "M," with "M" being determined as follows:

$$M = \frac{\text{Local Degree Days} \times \text{Average Local Heating Rate in Cents per M/Cu Ft}}{\text{Btu Content of Local Gas}}$$

or

$$M = \frac{\text{Local Degree Days} \times \text{Rate per Therm in Cents}}{100{,}000}$$

The following table gives the factor "F" for the most unusual types of building constructions. Figure local multiplier, "M," as outlined above, multiply M by F and then it is possible to fill in this table with the local constant which will be used in figuring the seasonal operating cost to offset the heat loss through any given area of wall, ceiling, or floor.

Type of Material	Factor "F"	Multiplier "M"	Final constant
Single glass	0.000352	.....	.....
Double glass	0.000143	.....	.....
Walls:			
8" Brick, sheathing, stud, L&P.	0.000085	.....	.....
Stucco, wood, and plaster	0.000099	.....	.....
Stone, tile, furred, L&P	0.000077	.....	.....
Clapboards, studding, L&P	0.000080	.....	.....
Floors:			
Wood floor. No. ceiling below	0.000042	.....	.....
Double floor. L&P below	0.000022	.....	.....
Ceilings:			
Plaster board and plaster	0.000098	.....	.....
Rigid insulation and plaster	0.000056	.....	.....
Roofs:			
Tile or slate on wood	0.000179	.....	.....
Shingles, sheathing, stud, L&P.	0.000102	.....	.....
Volume:			
To offset air infiltration:			
One air change per hour	0.0000058	.....	.....
One and one-half air changes	0.0000087	.....	.....
Two air changes per hour	0.0000116	.....	.....

NOTE: For any wall construction not listed above which may be found to be common in the locality, the factor "F" may be obtained by:
Coefficient of Transmission $\times$ 0.00032 = F

After the above final constants for the territory have been worked out, it is recommended that they be printed on a survey card arranged along the lines of the one reproduced here. The reverse side of the card can carry the usual general information as to the prospect's name and address, date of survey, and the like.

With permission, from Surface Combustion Corp.

SUGGESTED FORM FOR RAPID SURVEY METHOD

Area sq. ft.	Material	Local factor	Operating cost per season
....	Glass: Single	....	$.....
....	Glass: Double	....	.....
....	Walls (net): 8″ brick	....	.....
....	Stucco, tile and plaster	....	.....
....	Stone, tile, furred, L&P	....	.....
....	Clapboards, studding, L&P	....	.....
....	.....	....	.....
....	Floors: Wood floor, no ceil. below	....	.....
....	Double floor: L&P below joists	....	.....
....	.....	....	.....
....	Roofs: Tile or slate on wood	....	.....
....	Shingles, sheathing, studding, L&P	....	.....
....	.....	....	.....
Cu. ft.	Volume		
....	Infiltration: 1 air change per hr	....	.....
....	1½ air changes per hr	....	.....
....	2 air changes per hr	....	.....
	.....		
	Total operating cost per season	....	$.....

If Btu heat loss per hour is desired, use formula $= \frac{218{,}750 \times \text{Season's Cost}}{M}$

HEAT DELIVERY OF SPACE HEATING EQUIPMENT

STEAM: 1 sq ft cast iron radiation = 240 Btu/hr (2 Lb steam 70 F room temp)

HOT WATER: 1 sq ft cast iron radiation = 150 Btu/hr 70 F room temp

FORCED HOT WATER: 1 sq ft cast iron radiation = 200 Btu/hr (70 F room temp)

GRAVITY WARM AIR: 1 sq in. of basement duct (175 F register temp)

= 110 Btu/hr on first floor

= 166 Btu/hr on second floor

= 200 Btu/hr on third floor

FORCED WARM AIR: *The following formula gives the heat delivered at the register of a forced warm air heating system.*

$$H = A \times V \times 60 \times W \times S \times (t_d - t_r)$$

Symbols:

H = Heat delivered in Btu per hour.

A = Net area of discharge register in sq ft.

V = Velocity of air leaving register in ft per minute.

W = Weight of air at temperature t_d in pounds per cubic foot.

S = Specific heat of air in Btu per pound per degree F at temperature t_d.

t_d = Temperature in degrees F of air leaving register.

t_r = Temperature in degrees F of space being heated.

* With permission, "Surface Combustion Industrial Heating Handbook."

EXAMPLE

CONDITIONS

Assume the following conditions for the computation of the seasonal operating cost in a home:

Two and one-half story residence

Walls: 8″ brick, lath and plaster inside over sheathing

Ceilings second floor: Plaster board and plaster

No flooring in attic

Floors: Frame construction, single thickness

Single glass windows

Air changes per hour: 1

Gross wall area:
- First floor, 1300 sq ft
- Second floor, 1150 sq ft

Glass area:
- Windows and doors
- First floor, 190 sq ft
- Second floor, 130 sq ft

Area second floor ceiling: 1010 sq ft

Area first floor: 1010 sq ft

Cubical contents:
- First floor, 9100 cu ft
- Second floor, 8700 cu ft
- Degree days 6000
- Gas rate 40c/M cu ft
- Btu content 530

PRELIMINARY

$$M = \frac{6000 \times 40}{530} = 453$$

Final constant for glass area	=	.000352 × 453	= .159
Final constant for wall area	=	.000085 × 453	= .0385
Final constant for floor area	=	.000042 × 453	= .019
Final constant for ceiling area	=	.000098 × 453	= .044
Final constant for infiltration	=	.0000058 × 453	= .0026

SOLUTION

320 square feet glass area	×	.159	=	$ 50.88
2,130 square feet wall area	×	.0385	=	82.00
1,010 square feet floor area	×	.019	=	19.19
1,010 square feet ceiling area	×	.044	=	44.44
17,800 cubic feet infiltration	×	.0026	=	46.28
				$242.79

REQUIRED WATER HEATER CAPACITIES

Capacity of Hot Water Equipment Needed to Supply Fixtures in Various Types of Buildings

Gallons Per Maximum Hour

Fixture	Apt. house	Club	Gymna-sium	Hos-pital	Hotel	Indst. plant	Laun-dry	Office bldg.	Public bath	Private house	School	Y.W.C.A. Y.M.C.A.
Wash basin (private)	3	3	3	3	3	3	3	3	3	3	3	3
Wash basin (public)	5	8	10	10	10	15	10	15	15	..	15	15
Bath tub	15	15	30	15	15	30	..	..	45	15	..	30
Dish washer	15	30	..	30	30	30	..	..	..	15	15	..
Foot basin	3	3	..	3	3	..	..	..	..	3	..	10
Kitchen sink	10	20	..	20	20	20	..	..	..	10	10	20
Laundry tub (stationary)	25	35	..	35	35	..	45	..	45	25	..	45
Laundry tub (revolving)	75	75	..	100	150	..	100	..	100	75	..	100
Pantry sink	10	20	..	20	20	..	10	..	..	10	20	20
Shower	100	200	300	100	100	300	..	..	300	100	300	200
Slop sink	20	20	..	20	30	20	..	20	20	15	20	20
Dish washer	250 gallons per hour for each 500 people											
% of total water likely be drawn in one hour	20	30	60	40	30	70	80	15	80	30	25	30

Buenger, A. Journ. A.S.H. & V. E.

APPROXIMATE FUEL CONSUMPTIONS FOR WATER HEATING

Fuel	Btu in Unit as Sold	Typical Overall efficiency	Fuel Consumption per Month, (based on a daily draw of 50 gallons, or 1500 gallons of hot water monthly)
Gas:			
Manufactured	530 Btu per cubic foot	68–61%	2690–2940 cubic feet
Natural	1100 Btu per cubic foot	68–61%	1350–1475 cubic feet
Mixed	Varies with mixture	68–61%	Consult local compnay
Electricity	3412 Btu per Kwh	86–74%	340–390 Kwh
Oil:			
Summer	138,000 Btu per gallon	20– 8%	36–87 gallons
Winter	138,000 Btu per gallon	45–20%	16–34 gallons
Kerosene	136,000 Btu per gallon	40–25%	18–28 gallons
Coal:			
Indirect heater	12,000 Btu per pound	27–24%	305–350 pounds
Furnace coil	12,000 Btu per pound	28–24%	302–348 pounds
Pot stove	12,000 Btu per pound	17–13%	504–656 pounds

CAPACITY OF PIPE

Cubic feet of gas per hour 0.3" pressure drop; 0.6 spec. gr.

Length of pipe (ft.)	Diameter of pipe inches							
	½	¾	1	1¼	1½	2	3	4
15	76	172	345	750	1,220	2,480	6,500	13,880
30	52	120	241	535	850	1,780	4,700	9,700
45	43	99	199	435	700	1,475	3,900	7,900
60	38	86	173	380	610	1,290	3,450	6,800
75		77	155	345	545	1,120	3,000	6,000
90		70	141	310	490	1,000	2,700	5,500
105		65	131	285	450	920	2,450	5,100
120			120	270	420	860	2,300	4,800
150			109	242	380	780	2,090	4,350
180			100	225	350	720	1,950	4,000
210			92	205	320	660	1,780	3,700
240				190	300	620	1,680	3,490
270				178	285	580	1,580	3,250
300				170	270	545	1,490	3,000

MULTIPLIERS

To convert gas flow at 0.6 spec. grav. to flow at another gravity

Specific gravity	Multiplier
2.0	0.547
1.5	0.633
1.4	0.654
1.3	0.680
1.2	0.707
1.1	0.740
1.0	0.775
0.9	0.817
0.8	0.866
0.7	0.926
0.6	1.000
0.5	1.095
0.4	1.225

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COMPARISON OF GAS AND ELECTRICITY IN COMMERCIAL COOKING

The opportunity was provided for making a study by the replacement of the commercial cooking equipment in Alfonso's Restaurant in Washington, D. C., where a careful record was kept of operating conditions, meals served and utility consumptions. As a result, replacement factors for gas and electricity in a typical commercial cooking establishment were obtained, that were based on long periods of practical operation under identical conditions.

RESULTS OF STUDY

New Gas Equipment Versus New Electric Equipment

Electricity used for cooking during the months, October, 1946 — through July, 1947: 116,190 kwh.

Gas used for cooking during the ten months from October, 1947, through July, 1948, totaled 5,434 therms.

Electric cooking equipment having a rating of 82.8 kw added 45.15 kw to the maximum demand, which amounted to 54 per cent of the connected load.

When electricity was used for cooking, average monthly consumption:

Cooking only	11,619 kwh
Lights and other uses	3,601 kwh
Total for all purposes	15,220 kwh

Maximum electric billing demand (Connected cooking load of kitchen 82.8 kw)

Cooking only	45.15 kw
Lights and other uses	14.75 kw
Total demand	59.90 kw

When gas was used for cooking:

Average monthly consumption of gas for cooking . . . . . 543 therms

Average monthly consumption of electricity for lights and other uses 3601 kwh

Maximum electric billing demand for lights and other uses . . . . . 14.75 kw

The data obtained in this study furnish authentic replacement factors indicating the relative consumptions of gas and electricity for commercial kitchen operation, typified by Alfonso's Restaurant:

Heating value of gas Btu	1000 cu. ft. are equivalent to this this many kwh	1 kwh is equivalent to this many cubic feet
525	112.1	8.90
540	115.2	8.65
850	181.9	5.50
1,000	213.7	4.68
1,100	235.1	4.25
2,500	534.0	1.87

1.371 Btu of gas are equivalent to 1 Btu of electricity
.0468 therms of gas are equivalent to 1 kwh of electricity
1 therm of gas is equivalent to 21.4 kwh of electricity

These factors are based upon actual amounts of gas and electricity used for cooking purposes without correction for the difference in the number of meals served, although this results in a slight benefit to electricity. Actually, 1 per cent more meals were cooked with gas.

"A Comparison of Gas and Electric Usage for Commercial Cooking," American Gas Association.

RELATIVE COST OF GAS AND ELECTRIC COOKING

The conclusions reached by the American Gas Association in their Bulletin No. 6 are as follows:

Item	Scope of Test	Energy Ratio
1.	Top burner performance	1.532
2.	Oven performance	2,624
3.	Week's menu (upper income)	2.077
4.	Week's menu (limited income)	1.799
5.	Foor for Infant	1.754

Accepting an energy ratio of 1.9 the following formula will facilitate calculators:

$$\frac{1.9 \times 3413}{\text{Btu of Gas}} = \text{cu ft of gas equivalent to 1 Kwh.}$$

in which if 525 Btu. per cu ft of gas is being burned, then by substitution

$$\frac{1.9 \times 3413}{525} = 12.35 \text{ cu ft of gas equivalent to 1 Kwh.}$$

With the foregoing as a basis, the tabulation below represents the "break even" gas cost per Mcf for electricity at different costs per Kwh, fuel cost only being considered on a 1.9 energy ratio.

Cost per Kwh., cents	Break-even cost per Mcf. Btu of gas per cu. ft.					
	500	525	550	750	1000	1100
1.0	$0.77	$0.81	$0.85	$1.16	$1.54	$1.70
1.5	1.16	1.21	1.37	1.73	2.31	2.54
2.0	1.54	1.62	1.70	2.32	3.08	3.40
2.5	1.93	2.02	2.12	2.89	3.86	4.24
3.0	2.32	2.42	2.54	3.46	4.62	5.08
3.5	2.70	2.83	2.97	4.05	5.40	5.94
4.0	3.08	3.24	3.40	4.64	6.16	6.80
5.0	3.86	4.04	4.24	5.78	7.72	8.48

COMMERCIAL COOKING AND BAKING REQUIREMENTS

In Btu per meal served

Class	Electricity	Gas	Oil	Coal
Clubs, first class	4,270	8,280	11,450	15,750
Hotels, first class	3,415	6,620	9,200	12,650
Cafeteria, first class	2,140	4,080	5,670	7,800
Institutions	1,708	3,340	4,630	6,360
Hospitals	1,280	2,490	3,450	4,750
College mess halls	482	935	1,300	1,785

Steam tables, coffee urns, hot water, dish washing, etc., adds 30 to 50 per cent to the above figures.

With permission, "Surface Combustion Industrial Heating Handbook."

LOWEST RECORDED TEMPERATURES AND ANNUAL DEGREE DAYS FOR CITIES OF UNITED STATES AND CANADA[1]

DEGREE DAY is a term used to express the intensity of the heating season. It is the difference between 65° F. and the daily mean temperature. The sum of these differences for every day of the heating season is the total degree days for the year. Experience has shown that the gas heating season starts when the monthly mean temperature is 65° F., and that gas consumption for house heating is proportional to the drop in temperature below 65° F.

City	Min. Temp.	Degree-Days
Alabama		
Anniston	3	2813
Gadsden	—13	3006
Montgomery	— 5	1886
Tuscaloosa	— 7	2529
Arizona		
Flagstaff	—25	7145
Tucson	6	1845
Arkansas		
Bergman	—17	3596
Little Rock	—12	2811
Texarkana	— 7	2216
California		
Bakersfield	13	2047
Fresno	17	2375
Los Angeles	28	1504
Sacramento	19	2654
San Diego	25	1645
San Francisco	29	3264
Colorado		
Buena Vista	—37	8849
Colorado Springs	—27	6553
Denver	—29	5873
Pueblo	27	5514
Connecticut		
Hartford	—18	6037
New Haven	—14	5895
Delaware		
Wilmington	—12	4788
District of Columbia		
Washington	—15	4626
Florida		
Monticello	16	1129
Tampa	9	296
Georgia		
Atlanta	— 8	2891
Augusta	3	2161
Macon	— 4	2203
Savannah	8	1490
Idaho		
Boise	—28	4558
Springfield	—28	7477
Illinois		
Chicago	—23	6315
Joliet	—25	6535
Springfield	—24	5370
Indiana		
Evansville	—16	4164
Fort Wayne	—24	5916
Indianapolis	—25	5297
South Bend	—20	6076
Iowa		
Davenport	—27	6287
Des Moines	—30	6373
Dubuque	—32	6788
Sioux City	—35	7023
Kansas		
Emporia	—23	4792
Topeka	—25	5301
Wichita	—22	4877
Kentucky		
Lexington	—20	4616
Louisville	—20	4180
Louisiana		
Baton Rouge	2	1349
New Orleans	7	1023
Shreveport	— 5	1938
Maine		
Bar Harbor	—21	7643
Portland	—21	7012
Maryland		
Baltimore	— 7	4333
Frederick	No. Fig	5928
Massachusetts		
Boston	—14	6145
Fitchburg	—17	6732
Williamstown	—26	7221
Michigan		
Ann Arbor	—21	6865
Cadillac	—36	7967
Detroit	—28	6494
Grand Rapids	—24	6534
Kalamazoo	—25	6625
Lansing	—26	7112
Sault Ste. Marie	—37	9281
Minnesota		
Duluth	—41	9480
Minneapolis	—33	7851
Rochester	—42	8123
Mississippi		
Columbia	9	1740
Corinth	— 8	3411
Tupelo	— 7	2780
Vicksburg	— 1	1809
Missouri		
Grand City	—29	5659
Jefferson City	—25	4874
Kansas City	—22	5202
St. Louis	—22	4585
Montana		
Billings	—49	7115
Butte	—33	8271
Helena	—42	8054
Nebraska		
Dumas	—31	7203
Omaha	—32	6128
Nevada		
Las Vegas	8	2842
Reno	—19	5891
New Hampshire		
Concord	—35	6852
Hanover	—37	8063
Keene	—28	7457
New Jersey		
Atlantic City	— 7	5175
Dover	—21	5970
Newark	—13	5387
New Brunswick	—15	5405
Sussex	—24	6134
Trenton	—13	4934
New Mexico		
Albuquerque	—10	4303
Sante Fe	—13	6063
New York		
Albany	—24	6889
Buffalo	—14	6821
Ithaca	—22	6719
New York City	—13	5348
Ogdensburg	—43	7490
Plattsburg	—25	7894
Rochester	—14	6733
Saranac Lake	—39	8673
Syracuse	—22	6592
North Carolina		
Asheville	No. Fig.	4263
Greensboro	— 3	3527
Wilmington	5	2302
North Dakota		
Bismarck	—45	8494
Hannah	—54	10714
Ohio		
Akron	—20	6069
Cincinnati	—17	4702
Cleveland	—17	6154
Columbus	—20	5323
Oklahoma		
Hugo	— 3	2648
Oklahoma City	—17	3613
Tulsa	—15	3560
Oregon		
Portland	— 2	4468
Wallowa	—38	7360
Pennsylvania		
Erie	—16	5866
Gettysburg	—20	5580
Philadelphia	— 6	4855
Pittsburgh	—20	5235
Reading	—14	5388
Scranton	—15	6129
Rhode Island		
Providence	—12	6014
South Carolina		
Charleston	7	1769
Columbia	— 2	2364
Spartanburg	— 4	3257
South Dakota		
Aberdeen	—46	8709
Jefferson	—48	8419
Tennessee		
Knoxville	—16	3670
Memphis	— 9	2950
Nashville	—13	3578
Texas		
Austin	— 1	1578
Dallas	—10	2455
Eagle Pass	— 7	871
Galveston	8	1016
San Antonio	4	1202
Utah		
Provo	—23	6184
Salt Lake City	—20	5553
Vermont		
Burlington	—28	7620
Northfield	—41	8420
Virginia		
Fredericksburg	—21	4243
Roanoke	—12	4068
Richmond	— 3	3725
Washington		
Seattle	3	4868
Spokane	—30	6353
Walla Walla	—17	4809
West Virginia		
Charleston	—17	3786
Huntington	—24	4734
Wheeling	No. fig.	5249
Wisconsin		
Green Bay	—36	7823
Milwaukee	—25	7372
Superior	—35	9750
Wyoming		
Casper	—30	6979
Cheyenne	—38	7462
Canada		
Vancouver, B. C.		5976
Winnipeg, Man.		11166
Toronto, Ont.		7732
Montreal, Que.		8705
Quebec, Que.		8628

[1]*From AGA "Househeating" and U. S. Weather Bureau.*

INDUSTRIAL HEATING OPERATIONS

Materials, operations and approximate temperature range

Material	Operation	Approx. Temp. Range (°F)
Aluminum alloy	Aging	250–460
Aluminum alloy	Annealing	450–775
Aluminum alloy	Forging	750–900
Aluminum alloy	Heat treating	310–1000
Aluminum	Melting	1200–1400
Aluminum alloy	Die casting	1250–1400
Antimony	Melting polint	1166
Asphalt	Melting	350–450
Babbitt	Melting	600–800
Brass	Annealing	600–900
Brass	Extruding	1400–1450
Brass	Forging	1200–1400
Brass, yellow	Melting	1705
Brass, red	Melting	1830
Bread	Baking	300–500
Brick	Burning	1800–2600
Brick, refractory	Burning	2500–3000
Bronze, 5% alum.	Melting	1940
Bronze, man.	Melting	1645
Bronze, phos.	Melting	1920
Bronze, tobin	Melting	1625
Cadmium	Melting point	610
Cake (food)	Baking	300–350
Calcium	Melting point	1562
Calender rolls	Heating	300
Candy	Cooking	225–300
Cast iron	Annealing	1600–1700
Cast iron	Malleablizing	1650–1800
Cast iron	Vitreous enameling	1200–1300
Cement	Kiln firing	2800–3000
China	Glazing	1500–1900
Clay, refrac.	Burning	2200–2600
Cobalt	Melting point	2714
Coffee	Roasting	600–800
Coke	By-product oven	1830–2730
Cookies	Baking	375–450
Copper	Annealing	800–1200
Copper	Refining	2100–2600
Copper	Melting	2100–2300
Copper	Smelting	2100–2600
Cores, sand	Baking	250–550
Cupronickel, 15%	Melting	2150
Cupronickel, 30%	Melting	2240
Electrotype	Melting	740
Enamel	Baking	250–450
Everdur 1010	Melting	1865
Frit	Smelting	2000–2400
Glass	Annealing	800–1200
Glass	Melting, pot furnace	2300–2500
Glass, bottle	Melting, tank furnace	2500–2900
Glass, flat	Melting, tank furnace	2500–3000
Gold	Melting	1950–2150
Iron	Blast furnace tap.	2500–2800
Iron, malleable	Melting	2400–3100
Iron, malleable	Annealing	1500–1700
Japan	Baking	300– 450
Lacquer	Drying	150–200
Lead	Melting	620–750
Lead	Blast furnace	1650–2200
Lead	Refining	1800–2000
Magnesium	Aging	350–400
Magnesium	Heat treating	730–760
Magnesium	Melting	1250–1300
Magnesium	Superheating	1450–1650
Meat	Smoking	100–150
Mercury	Melting point	–38
Molds, foundry	Drying	400–750
Molybdenum	Melting point	4757
Monel metal	Annealing	1100–1480
Monel metal	Melting	2800
Muntz metal	Melting	1660
Nickel	Annealing	1100–1480
Nickel	Melting	2650
Palladium	Melting point	2829
Phosphorous, yellow	Melting point	111
Pie	Baking	500
Pigment	Calcining	1600
Platinum	Melting	3224
Porcelain	Burning	2600
Potassium	Melting point	145
Potato chips	Frying	350–400
Primer	Baking	300–400
Silicon	Melting point	2606
Silver	Melting	1750–1900
Sodium	Melting point	208
Solder	Melting	400–600
STEEL		
Steel, Sheet	Blue annealing	1400–1600
Sheet	Box annealing	1500–1700
Sheet	Bright annealing	1250–1350
Sheet	Job mill heating	2000–2100
Sheet	Mill heating	1800–2100
Sheet	Open annealing	1500–1700
Sheet	Tin plating	650
Sheet	Vitreous enameling	1400–1650
Sheet, tin plate	Box annealing	1200–1650
Sheet, tin plate	Hot mill heating	1800–2000
Sheet, tin plate	Lithographing	300
Steel	Bessemer converter	2800–3000
Steel	Calorizing	1700
Steel	Carburizing	1500–1700
Steel	Case hardening	1600–1700
Steel	Cyaniding	1400–1800
Steel	Drawing forgings	850
Steel	Drop forging	2200–2400
Steel	Forging	1700–2150
Steel	Form-bending	1600–1800
Steel	Galvanizing	800–900
Steel	Heat treating	700–1800
Steel	Lead hardening	1400–1800
Steel	Melting, open hearth	2800–3100
Steel	Melting, electric furn.	2400–3200
Steel	Normalizing	1650–1900
Steel	Rolling	2300
Steel	Soaking pits	1900–2100
Steel	Upsetting	2000–2300
Steel	Welding	2400–2800
Steel bars	Heating	1900–2200
Steel billets	Heating	2250
Steel blooms	Heating	2250
Steel bolts	Heading	2200–2300
Steel castings	Annealing	1300–1600
Steel flanging	Heating	1800–2100
Steel ingots	Heating	2000–2200
Steel nails	Blueing	650
Steel pipe	Butt welding	2400–2600
Steel rails	Hot bloom reheating	1900–2050
Steel rivets	Heating	2000–2200
Steel rod	Mill heating	1900–2100
Steel shape	Heating	1900–2200
Steel slabs	Heating	2000–2200
Steel spikes	Heating	2000–2200
Steel springs	Annealing	1500–1650
Steel wire	Annealing	1200–1400
Steel wire	Pot annealing	1650
Steel wire	Baking	300–350
Steel, alloy tool	Hardening	1425–2150
Steel, alloy tool	Preheating	1200–1500
Steel, alloy tool	Tempering	325–1250
Steel, carbon	Hardening	1360–1550
Steel, carbon tool	Hardening	1450–1500
Steel, carbon	Tempering	300–1100
Steel, carbon tool	Tempering	300–550
Steel, hi-carbon	Annealing	1400–1500
Steel, hi-speed	Hardening	2250–2375
Steel, hi-speed	Preheating	1450–1600
Steel, hi-speed	Tempering	1000–1150
Steel, S.A.E.	Annealing	1400–1650
Tin	Melting	500–650
Type metal	Stereotyping	525–650
Type metal	Linotyping	550–650
Type metal	Electrotyping	650–750
Varnish	Cooking	520–600
Vitreous enamel	Firing	1400–1700
Zinc	Melting	800–900
Zinc alloy	Die casting	850

"Hauck Industrial Combustion Data." Copyright 1953, Hauck Manufacturing Co.

COMBUSTION CHARACTERISTICS OF TYPICAL GASES

(Calculated on dry basis)

Kind of Gas	Constituents of Gas—Per Cent by Volume										Specific gravity	Btu per cu. ft.		Cu. Ft. of air per cu. ft. of gas	Products of combustion per volume of gas			Ultimate % CO_2
	CO_2	O_2	N_2	CO	H_2	Ill.	CH_4	C_2H_6	C_3H_8	C_4H_{10}		gross	net		CO_2	H_2O vapor	N_2	
Natural gas, Kettleman Hills, California—Stripped casinghead	..	..	..	..	..	..	85.4	8.6	5.1	0.9	.67	1183	1071	11.06	1.215	2.215	8.742	12.2
Natural gas, Long Beach, Los Angeles basin, California—stripped casinghead	0.5	.	..	..	..	..	86.8	7.2	4.3	1.2	.66	1161	1051	10.87	1.194	2.184	8.587	12.2
Natural gas, San Joaquin Valley, California—dry	0.1	..	1.2	..	..	..	98.7	..	..	..	.56	1000	902	9.40	.987	1.974	7.442	11.7
Natural gas, Gulf Coast area, Texas—Stripped	0.2	1.0	7.7	..	..	..	88.8	2.3	..	..	.61	941	849	8.80	.934	1.845	7.027	11.7
Natural gas—Texas Panhandle	0.1	0.1	7.7	..	..	..	82.2	6.1	2.4	1.4	.67	1052	952	9.85	1.076	1.997	7.882	12.0
Natural gas, West Virginia	0.8	..	1.1	..	..	..	75.0	23.1	..	..	.69	1174	1064	11.00	1.212	2.193	8.700	12.2
Natural gas—casinghead, Unstripped	1.0	..	1.1	..	..	..	66.6	31.3	..	..	.74	1236	1122	11.56	1.292	2.271	9.148	12.4
Natural gas—sour	..	..	..	H_2S	6.4	..	58.7	16.5	9.9	8.5	.91	1478	1348	13.79	1.589 SO_2.064	2.589	11.094	12.5
Coal gas (Horizontal Retort)	2.1	0.4	3.5	8.7	50.5	3.8	28.2	2.8	..	..	.43	612	549	5.28	.568	1.240	4.241	11.8
Coal gas (Horizontal Retort)	2.8	0.6	8.8	7.4	41.6	4.5	34.3	..	..	..	.49	606	545	5.27	.589	1.206	4.299	12.1
Coal gas (Vertical retort)	3.0	0.6	3.1	7.0	50.4	3.1	32.8	..	..	..	.41	587	525	5.06	.527	1.231	4.060	11.5
By-product coke oven gas	2.1	0.4	6.1	5.0	52.9	3.2	30.3	..	..	..	.40	565	505	4.86	.476	1.209	3.935	10.8
By-product coke oven gas	1.5	0.3	5.0	5.0	58.0	2.8	27.4	..	..	..	.36	544	484	4.64	.429	1.192	3.741	10.3
By-product coke oven gas	2.5	0.8	10.1	11.1	47.6	3.4	24.5	..	..	..	.47	513	461	4.35	.490	1.044	3.571	12.1
By-product coke oven gas	2.3	1.5	12.0	7.8	46.8	4.0	24.6	1.0	..	..	.48	532	478	4.51	.495	1.082	3.723	11.7
Carburetted water gas—Gas oil enrichment	3.3	0.7	3.8	33.4	38.1	10.7	10.0	..	..	..	.65	563	520	4.53	.799	.827	3.822	17.3
Carburetted water gas—Heavy oil with blow-run	4.6	0.6	16.7	24.1	32.5	10.3	9.0	2.2	..	..	.71	535	494	4.38	.740	.808	3.825	16.2
Carburetted water gas—Heavy oil with blow-run	5.8	0.6	11.5	25.0	34.4	9.2	13.5	..	..	..	.68	527	485	4.32	.737	.826	3.717	16.5
Carburetted water gas—Heavy oil with reforming and blow run	5.3	0.6	12.8	21.9	36.5	8.3	14.6	..	..	..	.65	515	472	4.24	.684	.848	3.648	15.8
Carburetted water gas—High heating value	1.1	0.6	3.8	13.7	30.5	15.8	33.1	1.4	..	..	.63	820	753	7.23	.986	1.404	5.754	14.6
Uncarburetted water gas	6.2	0.3	3.0	39.2	49.0	..	2.3	..	..	..	.55	309	281	2.31	.477	.536	1.852	20.5
Butane air gas	..	17.6	66.4	..	..	..	..	..	..	16.0	1.17	544	503	4.11	.640	.800	3.915	14.1
Propane air gas	..	16.6	62.4	..	..	..	..	..	21.0	..	1.12	544	501	4.21	.630	.840	3.952	13.7
Propane air gas	..	14.5	54.6	..	..	..	..	..	30.9	..	1.17	801	737	6.67	.927	.1236	5.815	13.7
Refinery oil gas—liquid Phase cracking (cross Still)	..	0.2	0.6	1.2	6.1	5.0	4.4	72.5	..	..	1.00	1665	1530	15.35	1.926	2.654	12.208	13.6
Refinery oil gas—vapor Phase cracking (gyro Still)	0.1	1.0	..	1.2	13.1	39.6	23.3	21.7	..	..	.88	1465	1350	13.20	1.789	2.119	10.626	14.4
Reformed refinery oil gas	4.0	0.6	4.8	18.2	52.1	3.6	16.7	..	..	..	.47	476	429	3.93	.504	.938	3.189	13.6
Reformed natural gas—																		
Water gas generator	1.9	0.2	6.5	17.1	39.1	2.3	32.9	..	..	..	.50	566	511	4.91	.593	1.102	3.964	13.0
Oil gas	3.0	0.6	4.4	9.7	50.2	4.0	28.1	..	..	..	.44	567	509	4.85	.536	1.156	3.912	12.1
Producer gas—anthracite	6.6	..	49.0	25.1	18.7	0.3	0.3	..	..	..	.84	151	141	1.13	.330	.200	1.386	19.2
Producer gas—Bituminous	2.5	0.3	55.3	27.0	12.0	0.4	2.5	..	..	..	.87	160	151	1.23	.333	.179	1.529	17.9
Blast furnace gas	9.4	..	61.8	27.8	1.0	..	..	..	..	..	1.01	93	92	.69	.372	.010	1.160	24.3

AVERAGE ECONOMY OF INDUSTRIAL FURNACES WITH GOOD OPERATION

Process	Millions of Btu per net ton	Efficiency per cent
FERROUS PRODUCTS		
ngot heating, soaking pits	1.0	24
illet heating for forming batch—		
In-and-out type	3.5	20
Continuous non-recuperative	2.2	32
Bar annealing, pit or car type	2.6	17
Wire annealing—hood type, coils	2.7	16
strand in lead	2.2	19
strand, open fired	1.2	32
stainless, catenary strand	2.7	24
Caustic pickle, stainless wire coils	0.7	26
Wire temper, open heat, lead quench	4.0	19
Wire patenting, strands	2.5	20
Wire galvanizing, strands	0.8	30
Wire tinning, strands	0.4	35
Wire baking, coils, continuous	0.5	32
Nail galvanizing, retort	0.3	—
Nail blueing, continuous retort	0.4	—
Tube reheating, sizing mill	1.5	18
Tube annealing—Continuous, bright	1.2	35
batch, car type	1.5	28
Tube normalizing, continuous roll-down	1.7	33
Tube galvanizing	1.2	20
Skelp heating, butt weld—batch	3.8	20
continuous	3.0	25
Slab heating, continuous recuperative	1.6	43
Sheet bar heating—batch	2.2	22
continuous	1.7	29
Sheet and strip annealing, hood type—		
Carbon steels	1.2	27
Alloy steels	2.0	19
Strip annealing, continuous coils	1.6	24
Strip, bright annealing, strands	1.2	32
Sheet normalizing, continuous, wasters	3.5	17
Sheet galvanizing	1.0	24
Nickle stainless sheet anneal, strands	3.0	21
Caustic pickle stainless strip, continuous	0.3	—
Nickle stainless sheet anneal, batch	4.5	16
Enamelling — cast iron, three coats, batch	4.0	21
Flat ware, continuous	2.6	18
Hardening, continous conveyor type	2.5	20
Drawing, continous conveyor type	1.5	21
Carburizing, boxes, continuous	4.5	12
Carburizing, gas, continuous	3.0	18
Annealing steel castings	3.7	13
NON-FERROUS PRODUCTS		
Copper and brass—		
Billet or cake heating, continuous	0.8	30
Wire annealing — coils, continuous	1.5	16
strands, bright	1.1	22
Sheet and strip anneal, continuous, pans	0.8	30
Cartridge case anneal, continuous	1.3	19
Aluminum —		
Billet heating	1.4	32

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FUEL CONSUMPTION OF TYPICAL FURNACES

Brick, kilns:	Btu/1000 Brick
Hoffman continuous kiln	3,920,000-4,760,000
Ruebon kiln	5,880,000-9,240,000
Grates and trough	4,760,000-6,300,000
Staffordshire kiln	4,760,000-6,300,000
Buhrer continuous tunnel	3,220,000-3,900,000
Metal melting:	Btu/Ton
Iron and steel:	
Puddling	14,000,000
Open-hearth	3,000,000-6,500,000
Air furnace for malleable castings	8,600,000
Copper, reverberatory	4,200,000
Tin, smelting	19,200,000
Rolling-mill furnaces:	
Busheling	5,600,000-7,000,000
Billet heating	2,240,000-2,520,000
Billet heating (4 by 4)	2,800,000-4,200,000
Continuous furnace (cold billets)	1,500,000-2,250,000
Continuous-bloom furnace	1,400,000-2,100,000
Reheating cold blooms	1,960,000-2,800,000
Soaking pits (hoit to cold ingots)	250,000-2,000,000
Tire furnaces	4,500,000
Wheel furnaces	8,400,000
Sheet annealing	2,800,000
Tin-plate mill	2,500,000
Rivet making:	
Rivet-making furnaces	1,260,000
Forging:	
Drop forging or bolt heating	6,000,000-7,000,000
Ingot forging	4,000,000-5,000,000
Ingot forging (regeneration furnace)	3,500,000-4,000,000
Brass annealing	1,500,000-2,000,000
Heat-treatment:	
Casehardening	4,500,000-5,000,000
Quenching	2,000,000-3,000,000
Tempering	1,500,000-2,000,000

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PHYSICAL CLASSIFICATION OF REFRACTORIES

Refractory	PCE	High temp strength	Spalling resistance	Iron oxide slagging resistance[a]	Remarks
Silica	31–32	Excellent	Sensitive below 600°C	Fair	Widely used for sprung arches because of high-temperature strength
Fireclay	19–34	Fair	Fair depends on manufacture	Poor	General purpose material. Inexpensive
High-alumina	Above 38	Properties improve with increasing Al_2O_3			Used for more severe conditions than fireclay will withstand
Mullite	38	Excellent	Good	Good	
Magnesite	38 and above	Good	Sensitive. Depends somewhat upon manufacture	Superior	Expensive. Used in matallurgical furnaces. High heat capacity
Forsterite	Over 32	Excellent	Good	Excellent	Indicated where both high-temperature strength and resistance to slagging are needed
Chrome	38 and above	Good	Fair to good, depending on composition and manufacture	Excellent below 2800°F. Poor above that temp	Less expensive and somewhat less slag-resistant than magnesite. Same general type of applications
Silicon carbide	37 to above 38	Excellent	Superior	Fair to poor	Expensive. Used in contact with flames and for indirect heat transfer. Abrasion-resistant

[a] Resistance to slagging does not always control uses and applications. See last column under Remarks and context of chapter.

REPRESENTATIVE FUSION TEMPERATURES OF REFRACTORIES

	Fusing Temp, °C, of commercial refractories
Fused alumina	1750—2000
Bauxite	1565—2000
Mullite	1650—1820
Fireclay	1500—1750
Silica	1685—1800
Silicon carbide	1800—2240
Magnesite	2150—2165
Chrome	1850—2050
Spinel ($MgO.Al_2O_3$	2135

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GAS SAVINGS WITH PREHEATED AIR

1. The heat salvaged by recuperation may be utilized by any of the following means depending upon the process involved:
   a. The volume of gas used for a given job may be decreased.
   b. Production may be increased because of the greater quantity of heat available.
   c. Temperatures of the furnace may be increased.
2. Mathematical formulae is given below have been established for calculating the possible gas savings and theoretical probable increase in production due to preheated air:
   a. Formula for gas savings calculation

$$S = \frac{A}{G - F_G + A} \times 100.$$

S = per cent gas savings.
A = heat in air, Btu per cu ft of gas.
G = Average gross heating value of gas per cu ft.
F_G = flue loss above room temperature including latent heat of vaporization, Btu, per cu ft of gas.

   b. Formula for calculating possible increase in production.

$$S_w = \frac{P}{W_1} \times 100.$$

Where

S_w = percentage increase in work.
P = heat introduced by preheated air, Btu per hr above room temperature.
W_1 = heat absorbed by work with no preheat, Btu per hr.

3. Experimental tests have verified the correctness of the formula for
   a. Natural and coke oven gases (or any city gas.)
   b. Either reducing, neutral or oxidizing furnace atmospheres.
   c. Flue gas temperatures from 1400-2500° F.
   d. Preheated air temperatures from 80-1624° F.

4. From the results obtained it is concluded that the formula given in (2) is correct for all industrial gas furnace applications.

5. Gas savings in excess of 40 per cent have resulted when burning natural gas with preheated air at approximately 1600° F. The practicability of air preheated in excess of that temperature seems doubtful since the economic limit from the standpoint of investment for most installations would be exceeded.

With permission, "Surface Combustion Industrial Heating Handbook."

FUEL CONSUMPTION OF GAS ENGINES

The amount of gas required per hp hour is dependent upon the efficiency of the engine and the percentage of full load at which it is operating. As the hp output of the engine decreases, the fuel consumption per hp hour increases. For estimating purposes, the following figures may safely be used.

Per Cent of full load	Btu per hp hr
100	10,200
75	11,200
50	14,500
25	20,600

Inasmuch as most engines operate between 75 and 100 per cent of full load, the accepted practice is to figure 11,200 Btu per hp hour.

BTU PER BRAKE HORSEPOWER HOUR

Per Cent load	Small Bore below 7"	Large 5ore above 7"
100%	10,200	9,700
90%	10,300	9,900
80%	10,800	10,200
70%	11,300	10,900
60%	13,000	11,800
50%	14,500	13,000
40%	16,500	14,800
30%	19,000	17,000
20%	23,000	20,500

The above figures do not include the power required to operate the auxiliaries such as: cooling water pump, fan charging generator, etc.

The heat to be dissipated in a gas engine is approximately as follows:

Cooling water 3000 Btu per BHP hour or 50 Btu per minute per BHP.

Exhaust 3500 Btu per BHP hour or 59 Btu per minute per BHP.

The formula for figuring the quantity of cooling water required is as follows:

$$GPM = \frac{BHP \times Btu}{T \times 8.33}$$

where

GPM = Gallons per minute of cooling water

BHP = Brake horsepower load on engine

Btu = Heat to be dissipated — Btu per minute

T = Difference in cooling water temperature in and out.

The heat balance of a natural gas engine at full load is approximately as follows:

Brake horsepower	25%
*Friction	7%
Cooling Water	30%
Exhaust	35%
Radiation	3%

*The heat generated in friction is dissipated in the cooling water and radiation.

AGA Gas Engine Handbook.

BELLAMY DEMAND-CHARGE RATE FORMULA

For All Load Factors

$$\text{Demand-charge per Mcf gas delivered} = \frac{3.288 \times DC}{LF}$$

Where

DC = Demand-charge per Mcf of billing demand per month

LF = Load factor

Therefore,

$$\text{Price per Mcf of gas delivered} = \frac{3.288 \times DC}{LF} + \text{commodity charge}$$

Example:

(Assumed Gas Rate)

Demand charge = $2.10 per Mcf billing demand per month

Commodity charge = 21c per Mcf of gas delivered

To determine price of gas at 70 per cent load factor

Then

$$\text{Gas price per Mcf} = \frac{3.288 \times 210}{70} + 21 = 9.86 + 21 = 30.86c$$

HEATING VALUE OF PETROLEUM OILS

Crude Oils, Fuel Oils, and Kerosene

Gravity		Density	Total heat of combustion at constant volume, Q_v			Net heat of combustion at constant pressure, Q_p			Degrees A. P. I. at 60° F.
Degrees A. P. I. at 60° F.	Specific at 60°/60° F.	Pounds per gallon	Cal./g	Btu./lb.	Btu./gal.	Cal./g	Btu./lb.	Btu./gal.	
10	1. 0000	8. 337	10, 300	18, 540	154, 600	9, 740	17, 540	146, 200	**10**
11	. 9930	8. 279	10, 330	18, 590	153, 900	9, 770	17, 580	145, 600	11
12	. 9861	8. 221	10, 360	18, 640	153, 300	9, 790	17, 620	144, 900	12
13	. 9792	8. 164	10, 390	18, 690	152, 600	9, 810	17, 670	144, 200	13
14	. 9725	8. 108	10, 410	18, 740	152, 000	9, 840	17, 710	143, 600	14
15	. 9659	8. 053	10, 440	18, 790	151, 300	9, 860	17, 750	142, 900	**15**
16	. 9593	7. 998	10, 470	18, 840	150, 700	9, 880	17, 790	142, 300	16
17	. 9529	7. 944	10, 490	18, 890	150, 000	9, 900	17, 820	141, 600	17
18	. 9465	7. 891	10, 520	18, 930	149, 400	9, 920	17, 860	140, 900	18
19	. 9402	7. 839	10, 540	18, 980	148, 800	9, 940	17, 900	140, 300	19
20	. 9340	7. 787	10, 570	19, 020	148, 100	9, 960	17, 930	139, 600	**20**
21	. 9279	7. 736	10, 590	19, 060	147, 500	9, 980	17, 960	139, 000	21
22	. 9218	7. 686	10, 620	19, 110	146, 800	10, 000	18, 000	138, 300	22
23	. 9159	7. 636	10, 640	19, 150	146, 200	10, 020	18, 030	137, 700	23
24	. 9100	7. 587	10, 660	19, 190	145, 600	10, 040	18, 070	137, 100	24
25	. 9042	7. 538	10, 680	19, 230	145, 000	10, 050	18, 100	136, 400	**25**
26	. 8984	7. 490	10, 710	19, 270	144, 300	10, 070	18, 130	135, 800	26
27	. 8927	7. 443	10, 730	19, 310	143, 700	10, 090	18, 160	135, 200	27
28	. 8871	7. 396	10, 750	19, 350	143, 100	10, 110	18, 190	134, 600	28
29	. 8816	7. 350	10, 770	19, 380	142, 500	10, 120	18, 220	133, 900	29
30	. 8762	7. 305	10, 790	19, 420	141, 800	10, 140	18, 250	133, 300	**30**
31	. 8708	7. 260	10, 810	19, 450	141, 200	10, 150	18, 280	132, 700	31
32	. 8654	7. 215	10, 830	19, 490	140, 600	10, 170	18, 310	132, 100	32
33	. 8602	7. 171	10, 850	19, 520	140, 000	10, 180	18, 330	131, 500	33
34	. 8550	7. 128	10, 860	19, 560	139, 400	10, 200	18, 360	130, 900	34
35	. 8498	7. 085	10, 880	19, 590	138, 800	10, 210	18, 390	130, 300	**35**
36	. 8448	7. 043	10, 900	19, 620	138, 200	10, 230	18, 410	129, 700	36
37	. 8398	7. 001	10, 920	19, 650	137, 600	10, 240	18, 430	129, 100	37
38	. 8348	6. 960	10, 940	19, 680	137, 000	10, 260	18, 460	128, 500	38
39	. 8299	6. 920	10, 950	19, 720	136, 400	10, 270	18, 480	127, 900	39
40	. 8251	6. 879	10, 970	19, 750	135, 800	10, 280	18, 510	127, 300	**40**
41	. 8203	6. 839	10, 990	19, 780	135, 200	10, 300	18, 530	126, 700	41
42	. 8155	6. 799	11, 000	19, 810	134, 700	10, 310	18, 560	126, 200	42
43	. 8109	6. 760	11, 020	19, 830	134, 100	10, 320	18, 580	125, 600	43
44	. 8063	6. 722	11, 030	19, 860	133, 500	10, 330	18, 600	125, 000	44
45	. 8017	6. 684	11, 050	19, 890	132, 900	10, 340	18, 620	124, 400	**45**
46	. 7972	6. 646	11, 070	19, 920	132, 400	10, 360	18, 640	123, 900	46
47	. 7927	6. 609	11, 080	19, 940	131, 900	10, 370	18, 660	123, 300	47
48	. 7883	6. 572	11, 100	19, 970	131, 200	10, 380	18, 680	122, 800	48
49	7839	6. 536	11, 110	20, 000	130, 700	10, 390	18, 700	122, 200	49

Bureau of Standards, Misc. Publication No. 97.

Tabel 1.

Volatile Petroleum Products

Gravity		Density	Total heat of combustion at constant volume, Q_v			Net heat of combustion at constant pressure, Q_p			Degrees A. P. I. at 60° F.
Degrees A. P. I. at 60° F.	Specific at 60°/60° F.	Pounds per gallon	Cal./g	Btu./lb.	Btu./gal.	Cal./g	Btu./lb.	Btu./gal.	
50	0. 7796	6. 500	11, 120	20, 020	130, 100	10, 400	18, 720	121, 700	**50**
51	. 7753	6. 464	11, 140	20, 050	129, 600	10, 410	18, 740	121, 100	51
52	. 7711	6. 429	11, 150	20, 070	129, 000	10, 420	18, 760	120, 600	52
53	. 7669	6. 394	11, 160	20, 100	128, 500	10, 430	18, 780	120, 100	53
54	. 7628	6. 360	11, 180	20, 120	128, 000	10, 440	18, 800	119, 500	54
55	. 7587	6. 326	11, 190	20, 140	127, 400	10, 450	18, 810	119, 000	**55**
56	. 7547	6. 292	11, 200	20, 170	126, 900	10, 460	18, 830	118, 500	56
57	. 7507	6. 258	11, 220	20, 190	126, 400	10, 470	18, 850	118, 000	57
58	. 7467	6. 225	11, 230	20, 210	125, 800	10, 480	18, 870	117, 500	58
59	. 7428	6. 193	11, 240	20, 230	125, 300	10, 490	18, 880	116, 900	59
60	. 7389	6. 160	11, 250	20, 260	124, 800	10, 500	18, 900	116, 400	**60**
61	. 7351	6. 128	11, 270	20, 280	124, 300	10, 510	18, 920	115, 900	61
62	. 7313	6. 097	11, 280	20, 300	123, 700	10, 520	18, 930	115, 400	62
63	. 7275	6. 065	11, 290	20, 320	123, 200	10, 530	18, 950	114, 900	63
64	. 7238	6. 034	11, 300	20, 340	122, 700	10, 540	18, 960	114, 400	64
65	. 7201	6. 004	11, 310	20, 360	122, 200	10, 540	18, 980	113, 900	**65**
66	. 7165	5. 973	11, 320	20, 380	121, 700	10, 550	18, 990	113, 400	66
67	. 7128	5. 943	11, 330	20, 400	121, 200	10, 560	19, 010	112, 900	67
68	. 7093	5. 913	11, 340	20, 420	120, 700	10, 570	19, 020	112, 500	68
69	. 7057	5. 884.	11, 350	20, 440	120, 200	10, 580	19, 040	112, 000	69
70	. 7022	5. 855	11, 360	20, 460	119, 800	10, 580	19, 050	111, 500	**70**
72	. 6953	5. 797	11, 380	20, 490	118, 800	10, 600	19, 080	110, 600	72
74	. 6886	5. 741	11, 400	20, 530	117, 900	10, 610	19, 100	109, 700	74
76	. 6819	5. 685	11, 420	20, 560	116, 900	10, 630	19, 130	108, 800	76
78	. 6754	5. 631	11, 440	20, 600	116, 000	10, 640	19, 150	107, 900	78
80	. 6690	5. 578	11, 460	20, 630	115, 100	10, 650	19, 180	107, 000	**80**
82	. 6628	5. 526	11, 480	20, 660	114, 200	10, 670	19, 200	106, 100	82
84	. 6566	5. 474	11, 490	20, 690	113, 300	10, 680	19, 220	105, 200	84
86	. 6506	5. 424	11, 510	20, 720	112, 400	10, 690	19, 240	104, 400	86
88	. 6446	5. 375	11, 530	20, 750	111, 500	10, 700	19, 260	103, 500	88
90	. 6388	5. 326	11, 540	20, 780	110, 700	10, 710	19, 280	102, 700	**90**
92	. 6331	5. 278	11, 560	20, 810	109, 800	10, 720	19, 300	101, 900	92
94	. 6275	5. 232	11, 570	20, 830	109, 000	10, 740	19, 320	101, 100	94
96	. 6220	5. 186	11, 590	20, 860	108, 100	10, 750	19, 340	100, 300	96
98	. 6166	5. 140	11, 600	20, 880	107, 300	10, 760	19, 360	99, 500	98
100	. 6112	5. 096	11, 620	20, 910	106, 500	10, 770	19, 380	98, 700	**100**
105	. 5983	4. 988	11, 650	20, 970	104, 600	10, 790	19, 420	96, 800	105
110	. 5859	4. 885	11, 680	21, 020	102, 700	10, 810	19, 460	95, 100	110
115	. 5740	4. 786	11, 710	21, 070	100, 900	10, 830	19, 490	93, 300	115
120	. 5626	4. 691	11, 740	21, 120	99, 100	10, 850	19, 530	91, 600	120
125	. 5517	4. 599	11, 760	21, 170	97, 400	10, 860	19, 560	90, 000	**125**
130	. 5411	4. 511	11, 790	21, 210	95, 700	10, 880	19, 590	88, 400	130
135	. 5310	4. 427	11, 810	21, 250	94, 100	10, 900	19, 610	86, 800	135
140	. 5212	4. 345	11, 830	21, 290	92, 500	10, 910	19, 640	85, 300	140
145	. 5118	4. 267	11, 850	21, 330	91, 000	10, 920	19, 660	83, 900	145

Table 2.

HEATING VALUE OF PETROLEUM OILS

In most practical applications of the combustion of petroleum products, the process is carried out at constant pressure (atmospheric) and the water vapor formed in combustion is not condensed. For such processes, therefore, the net heat of combustion at constant pressure is the more significant quantity in making comparisons of fuels and in calculating the efficiencies of heating appliances.

Heats of Combustion of Crude Oils, Fuel Oils, and Kerosenes

The data on heats of combustion (heating values) given in Table I apply to petroleum oils free from water, ash, and sulphur with an estimated accuracy of 1 per cent. These data are based on experimental results obtained, on a total of 630 petroleum oils from 8 States and 10 foreign countries, by 5 groups of observers.

Heats of Combustion of Volatile Petroleum Products

The data on heats of combustion (heating values) given in Table II apply to volatile petroleum liquids in general with an estimated accuracy of 1 per cent. The values given are probably too high by 1 or 2 per cent for products containing unusually large amounts of aromatic hydrocarbons; for example, "vapor phase cracked" gasoline. The tabulated values should be increased by about 1 per cent to yield corresponding value for the heats of combustion of vapor (vaporized product); that is, for those instances in which the latent heat of vaporization is supplied by the external surroundings and not by the combustion of the product.

Bureau of Standards, Misc. Publication No. 97.

Heating Value of Fuel Oils

It is common practice in power applications to measure the specific gravity of fuel oils in degrees Baume rather than API as provided above. The following relation, based upon degrees Baume, is applicable to commercial fuel oils (specific gravity 35 to 10 deg Bé):

Higher Heating Value (Btu/pound) =

$$18{,}250 + 40\ (\text{deg Bé} - 10)$$

Commercial Standards, CS 12-29

OIL TEMPERATURE CORRECTION FACTORS

Oil Temperature Correction Factors — to 60°F.

Observed Temp. °F.	Degrees A. P. I. 5.0° to 9.9°	10.0° to 14.9°	15.0° to 19.9°	20.0° to 24.9°	25.0° to 29.9°	30.0° to 34.9°	35.0° to 39.9°	40.0° to 49.9°	50.0° to 59.9°
0	1.0215	1.0227	1.0235	1.0243	1.0251	1.0262	1.0276	1.0301	1.0347
2	1.0208	1.0219	1.0227	1.0235	1.0243	1.0253	1.0267	1.0291	1.0335
4	1.0201	1.0211	1.0219	1.0226	1.0234	1.0244	1.0258	1.0281	1.0324
6	1.0193	1.0203	1.0211	1.0218	1.0226	1.0236	1.0248	1.0271	1.0312
8	1.0186	1.0196	1.0203	1.0210	1.0217	1.0227	1.0239	1.0261	1.0301
10	1.0179	1.0188	1.0195	1.0202	1.0209	1.0218	1.0230	1.0251	1.0290
12	1.0171	1.0180	1.0187	1.0194	1.0201	1.0209	1.0221	1.0241	1.0278
14	1.0164	1.0173	1.0179	1.0185	1.0192	1.0200	1.0212	1.0231	1.0267
16	1.0157	1.0165	1.0171	1.0177	1.0184	1.0192	1.0203	1.0221	1.0255
18	1.0150	1.0158	1.0164	1.0169	1.0175	1.0183	1.0194	1.0211	1.0244
20	1.0144	1.0150	1.0156	1.0161	1.0167	1.0174	1.0184	1.0201	1.0232
22	1.0137	1.0142	1.0148	1.0153	1.0159	1.0165	1.0175	1.0191	1.0220
24	1.0129	1.0135	1.0140	1.0144	1.0150	1.0156	1.0166	1.0181	1.0209
26	1.0122	1.0127	1.0132	1.0136	1.0142	1.0148	1.0156	1.0171	1.0197
28	1.0115	1.0120	1.0125	1.0128	1.0133	1.0139	1.0147	1.0161	1.0186
30	1.0108	1.0112	1.0117	1.0120	1.0125	1.0130	1.0138	1.0151	1.0174
32	1.0100	1.0105	1.0109	1.0112	1.0117	1.0121	1.0129	1.0141	1.0162
34	1.0093	1.0097	1.0101	1.0104	1.0108	1.0112	1.0120	1.0131	1.0151
36	1.0085	1.0089	1.0093	1.0096	1.0100	1.0104	1.0110	1.0121	1.0139
38	1.0078	1.0082	1.0085	1.0088	1.0091	1.0095	1.0101	1.0110	1.0128
40	1.0071	1.0074	1.0077	1.0080	1.0083	1.0087	1.0092	1.0100	1.0116
42	1.0064	1.0067	1.0069	1.0072	1.0075	1.0078	1.0082	1.0090	1.0104
44	1.0057	1.0060	1.0062	1.0064	1.0066	1.0069	1.0073	1.0080	1.0093
46	1.0049	1.0052	1.0054	1.0056	1.0058	1.0061	1.0064	1.0070	1.0081
48	1.0042	1.0045	1.0046	1.0048	1.0050	1.0052	1.0055	1.0060	1.0070
50	1.0035	1.0037	1.0038	1.0040	1.0042	1.0043	1.0046	1.0050	1.0058
52	1.0028	1.0029	1.0030	1.0032	1.0034	1.0035	1.0037	1.0041	1.0046
54	1.0021	1.0022	1.0023	1.0024	1.0025	1.0026	1.0028	1.0030	1.0035
56	1.0014	1.0014	1.0015	1.0016	1.0017	1.0018	1.0018	1.0020	1.0023
58	1.0007	1.0007	1.0008	1.0008	1.0008	1.0009	1.0009	1.0010	1.0012
60	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
62	.9993	.9993	.9992	.9992	.9992	.9991	.9991	.9990	.9988
64	.9986	.9986	.9985	.9984	.9983	.9982	.9982	.9980	.9977
66	.9979	.9978	.9977	.9976	.9975	.9974	.9972	.9970	.9965
68	.9972	.9971	.9970	.9968	.9966	.9965	.9963	.9960	.9954
70	.9965	.9963	.9962	.9960	.9958	.9957	.9954	.9950	.9942
72	.9958	.9956	.9954	.9952	.9950	.9949	.9945	.9940	.9930
74	.9951	.9949	.9946	.9944	.9942	.9940	.9936	.9929	.9919
76	.9943	.9941	.9938	.9936	.9934	.9932	.9927	.9919	.9907
78	.9937	.9934	.9931	.9929	.9926	.9923	.9918	.9909	.9896
80	.9930	.9927	.9924	.9921	.9918	.9914	.9909	.9899	.9884
82	.9923	.9919	.9916	.9913	.9910	.9905	.9899	.9889	.9871
84	.9916	.9912	.9908	.9905	.9901	.9896	.9890	.9879	.9860
86	.9909	.9904	.9900	.9897	.9893	.9888	.9880	.9869	.9848
88	.9902	.9897	.9893	.9889	.9884	.9879	.9871	.9859	.9837
90	.9895	.9890	.9885	.9881	.9876	.9870	.9862	.9849	.9825
92	.9888	.9883	.9877	.9873	.9868	.9861	.9853	.9839	.9813
94	.9881	.9875	.9870	.9865	.9860	.9852	.9844	.9829	.9802
96	.9874	.9867	.9862	.9857	.9852	.9844	.9834	.9819	.9790
98	.9867	.9860	.9855	.9849	.9843	.9835	.9825	.9809	.9779
100	.9860	.9853	.9847	.9841	.9835	.9827	.9816	.9799	.9767
102	.9853	.9846	.9839	.9833	.9827	.9818	.9807	.9789	.9755
104	.9846	.9839	.9832	.9826	.9818	.9809	.9798	.9778	.9743
106	.9838	.9831	.9824	.9818	.9810	.9801	.9789	.9768	.9731
108	.9832	.9824	.9817	.9810	.9802	.9792	.9780	.9758	.9720
110	.9825	.9817	.9810	.9802	.9794	.9783	.9771	.9748	.9708
112	.9818	.9809	.9802	.9794	.9786	.9775	.9762	.9738	.9696
114	.9811	.9802	.9794	.9786	.9777	.9766	.9753	.9728	.9685
116	.9804	.9795	.9786	.9778	.9769	.9758	.9743	.9718	.9673
118	.9797	.9788	.9781	.9770	.9760	.9749	.9734	.9708	.9662
120	.9790	.9781	.9772	.9762	.9752	.9741	.9725	.9698	.9650

Compiled from Bureau of Standards Circular C410 (1936).

Multiply the volume of oil in the tank or car at the observed temperature by these factors to get the volume at 60 deg F.

ANNUITY TABLE

Amount per year resulting in an annuity of one dollar after number of years shown below.

Years	2%	2½%	3%	3½%	4%	4½%	5%	6%	7%	8%	9%	10%
1	$1.000000	$1.000000	$1.000000	$1.000000	$1.000000	$1.000000	$1.000000	$1.000000	$1.000000	$1.000000	$1.000000	$1.000000
2	0.495050	0.493827	0.492611	0.491400	0.490196	0.488998	0.487805	0.485437	0.483092	0.480769	0.478469	0.476190
3	.326755	.325137	.323530	.321934	.320349	.318773	.317209	.314110	.311052	.308034	.305055	.302115
4	.242624	.240818	.239027	.237251	.235490	.233744	.232012	.228012	.225228	.221921	.218669	.215471
5	.192159	.190247	.188355	.186481	.184627	.182792	.180975	.177396	.173891	.170456	.167092	.163797
6	.158526	.156550	.154597	.152668	.150762	.148878	.147017	.143363	.139796	.136315	.132920	.129607
7	.134512	.132495	.130506	.128545	.126610	.124701	.122820	.119135	.115553	.112072	.108691	.105405
8	.116510	.114467	.112456	.110477	.108528	.106610	.104722	.101036	.097468	.094015	.090674	.087444
9	.102515	.100457	.098434	.096446	.094493	.092574	.090690	.087022	.083486	.080080	.076799	.073641
10	.091327	.089259	.087231	085241	.083291	.081379	.079505	.075868	.072378	.069029	.065820	.062745
11	.082178	.080106	.078077	.076092	.074149	.072248	.070389	.066793	.063357	.060076	.056947	.053963
12	.074560	.072487	.070462	.068484	.066552	.064666	.062825	.059277	.055902	.052695	.049651	.046763
13	.068118	.066048	.064030	.062062	.060144	.058275	.056456	.052960	.049651	.046522	.043567	.040779
14	.062602	.060537	.058526	.056571	.054669	.052820	.051024	.047585	.044345	.041297	.038433	.035746
15	.057825	.055766	.053767	.051825	.049941	.048114	.046342	.042963	.039795	.036830	.034059	.031474
16	.053650	.051599	.049611	.047685	.045820	.044015	.042270	.038952	.035858	032977	.030300	.027817
17	.049970	.047928	.045953	.044043	.042199	.040418	.038699	.035445	.032425	.029629	.027046	.024664
18	.046702	.044670	.042709	.040817	.038993	.037237	.035546	.032357	.029413	.026702	.024212	.021930
19	.043782	.041761	.039814	.037940	.036139	.034407	.032745	.029621	.026753	.024128	.021730	.019547
20	.041157	.039147	.037216	.035361	.033582	.031876	.030243	.027185	.024393	.021852	.019546	.017460
21	.038785	.036787	.034872	.033037	031280	.029601	.027996	.025005	.022289	.019832	017617	.015624
22	.036631	.034647	.032747	.030932	.029199	.027546	.025971	.023046	.020406	.018032	.015905	.014005
23	.034668	.032696	.030814	.029019	.027309	.025682	024137	021278	.018714	016422	.014382	.012572
24	.032871	.030913	.029047	.027273	.025587	.023987	022471	.019679	.017189	.014978	.013023	.011300
25	.031220	.029276	.027428	.025674	.024012	.022439	.020952	.018227	.015811	013679	.011806	.010161
26	.029699	.027769	.025938	.024205	.022567	.021021	.019564	.016564	.014561	.0125071	.0107154	.0091590
27	.028293	.026377	.024564	.022852	.021239	.019719	.018292	.015697	.013426	.0114481	.0097349	.0082576
28	.026990	.025088	.023293	.021603	.020013	.018521	.017123	.014593	.012392	.0104889	.0088520	.0074510
29	.025778	.023891	.022115	.020445	.018880	.017415	.016046	.013580	.011449	.0096185	.0080557	.0067281
30	.024650	.022778	.021019	.019371	.017830	.016392	.015051	.012649	.010586	.0088274	.0073364	.0060927
31	.023596	.021739	.019999	.018372	.016855	.015443	.014132	.011792	.009797	.0081073	.0066856	.0054962
32	.022611	.020768	.019047	.017442	.015949	.014563	.013280	.011002	.009073	.0074508	.0060962	.0049717
33	.021687	.019859	.018156	.016572	.015104	.013745	.012490	.010273	.008408	.0068516	.0055617	.0044994
34	.020819	.019007	.017322	.015760	.014315	.012982	.011755	.009598	.007797	.0063041	.0050766	.0040737
35	.020002	.018206	.016539	.014998	.013577	.012270	.011072	.008974	.007234	.0058033	.0046358	.0036897
36	.019233	.017452	.015804	.014284	.012887	.011606	.010434	.008395	.006715	.0053447	.0042350	.0033431
37	.018507	.016741	.015112	.013613	.012240	.010984	.009840	.007857	.006237	.0049244	.0038703	.0030299
38	.017821	.016070	.014459	.012982	.011632	.010402	.009284	.007358	.005795	.0045389	.0035382	.0027469
39	.017171	.015436	.013844	.012388	.011061	.009856	.008765	.006894	.005387	.0041851	.0032356	.0024910
40	.016556	.014836	.013262	.011827	.010523	.009343	.008278	.006462	.005009	.0038602	.0029596	.0022594
41	.015972	.014268	.012712	.011298	.010017	.008862	.007822	.006059	.004660	.0035615	.0027079	.0020498
42	.015417	.013729	.012192	.010798	.009540	.008409	.007395	.005683	.004336	.0032868	.0024781	.0018600
43	.014890	.013217	.011698	.010325	.009090	.007982	.006993	.005333	004036	.0030341	.0022684	.0016880
44	.014388	.012730	.011230	.009878	.008665	.007581	.006616	.005006	.003758	.0028015	.0020767	.0015322
45	.013910	.012268	.010785	.009453	.008262	.007202	.006262	004700	.003500	.0025873	.0019017	.00139
46	.013453	.011827	.010363	.009051	.007882	.006845	.005928	.004415	.003260	.0023899	.0017416	.0012620
47	.013018	.011407	.009961	.008669	.007522	.006507	.005614	.004148	.003037	.0022080	.0015952	.0011468
48	.012602	.011006	.009578	.008306	.007181	.006189	.005318	.003897	.0023897	.0020403	.0014614	.0010415
49	.012204	.010623	.009213	.007962	.006857	.005887	.005040	.003664	.002639	.0018856	.0013389	.0009459
50	.011823	.010258	.008865	.007634	.006550	.005602	.004777	.003444	002460	.0017429	.0012269	.0008592

COMPOUND INTEREST

Amount of one dollar at compound interest after number of years indicated.

Years	2%	2½%	3%	3½%	4%	4½%	5%	6%	7%	8%	9%	10%
1	$1.02000	$1.02500	$1.03000	$1.03500	$1.04000	$1.04500	$1.05000	$1.06000	$1.07000	$ 1.08000	$1.09000	$ 1.10000
2	1.04040	1.05062	1.06090	1.07122	1.08160	1.09203	1.10250	1.12360	1.14490	1.16640	1.18810	1.21000
3	1.06121	1.07689	1.09273	1.10872	1.12486	1.14117	1.15763	1.19102	1.22504	1.25971	1.29503	1.33100
4	1.08243	1.10381	1.12551	1.14752	1.16986	1.19252	1.21551	1.26248	1.31080	1.36049	1.41158	1.46410
5	1.10408	1.13141	1.15927	1.18769	1.21665	1.24618	1.27628	1.33823	1.40255	1.46933	1.53862	1.61051
6	1.12616	1.15969	1.19405	1.22926	1.26532	1 30226	1.34010	1.41852	1 50073	1.58678	1.67710	1.77156
7	1.14869	1.18869	1.22987	1.27228	1.31593	1.36086	1.40710	1.50363	1.60578	1.71382	1.82804	1.94872
8	1.17166	1.21840	1.26677	1.31681	1.36857	1.42210	1.47746	1.59385	1.71819	1.85093	1.99256	2.14359
9	1.19509	1.24886	1.30477	1.36290	1.42331	1.48610	1.55133	1.68948	1.83846	1.99900	2.17189	2.35795
10	1.21899	1.28008	1.34392	1.41060	1.48024	1.55297	1.62889	1.79085	1.96715	2.15892	2.36736	2.59374
11	1.24337	1.31209	1.38423	1.45997	1.53945	1.62285	1.71034	1.89830	2.10485	2.33164	2.58043	2.85312
12	1.26824	1.34489	1.42576	1.51107	1.60103	1.69588	1.79586	2.01220	2.25219	2.51817	2.81266	3.13843
13	1.29361	1.37851	1.46853	1.56396	1.66507	1.77220	1.88565	2.13293	2.40985	2.71962	3.06580	3.45227
14	1.31948	1.41297	1.51259	1.61869	1.73168	1.85194	1.97993	2.26090	2.57853	2.93719	3.34173	3.29773
15	1.34587	1.55830	1.55797	1.67535	1.80094	1.93528	2.07893	2.39656	2.75903	3.17217	3.64248	4.17725
16	1.37279	1.48451	1.60471	1.73399	1.87298	2.02237	2.18287	2.54035	2.95216	3.42594	3.97031	4.59497
17	1.40024	1.52162	1.65285	1.79467	1.94790	2.11338	2.69277	2.69277	3.15882	3.70002	4.32763	5.05447
18	1.42825	1.55966	1.70243	1.85749	2.02582	2.20848	2.40662	2.85434	3.37993	3.99602	4.71712	5.55992
19	1.45681	1.59865	1.75351	1.92250	2.10685	2.30786	2.52695	3.02560	3.61653	4.31570	5.14166	6.11591
20	1.48595	1.63862	1.80611	1.98979	2.19112	2.41171	2.65330	3.20714	3.86968	4.66096	5.60441	6.72750
21	1.51567	1.67958	1.86029	..05943	2.27877	2.52024	2.78596	3.39956	4.14056	5.03383	6.10881	7.40025
22	1.54598	1.72157	1.91610	2.13151	2.36992	2.6365	2.92526	3.60354	4.43040	5.43654	6.65860	8.14027
23	1.57690	1.76461	1.97359	2.20611	2.46472	2.75217	3.07152	3.81975	4.74053	5.87146	7.25787	8.95430
24	1.60844	1.80873	2.03279	2.28333	2.56330	2.87601	3.22510	4.04893	5.07237	6.34118	7.91108	9.84973
25	1.64061	1.85394	2.09378	2.36324	2.66584	3.00543	3.38635	4.29187	5.42743	6.48848	8.62308	10.83471
26	1.67342	1.90029	2.15659	2.44596	2.77247	3.14068	3.55567	4.54938	5.80735	7.39635	9.39916	11.91818
27	1.70689	1.94780	2.22129	2.53157	2.88337	3.28201	3.73346	4.82235	6.21387	7.98806	10.24508	13.10999
28	1.74102	1.99650	2.28793	2.62017	2.99870	3.42970	3.92013	5.11169	6.64884	8.62711	11.16714	14 29000
29	1.77584	2.04640	2.35657	2.71188	3.11865	3.58404	4.11614	5.41839	7.11426	9.31727	12.17218	15.86309
30	1.81136	2.09757	2.42726	2.80679	3.24340	3.74532	4.32194	5.74349	7.61226	10.06266	13.26768	17.44940
31	1.84759	2.15000	2.50008	2.90503	3.37313	3.91386	4.53804	6.08810	8.14511	10.86767	14.46177	19.19434
32	1.88454	2.20376	2.57508	3.00671	3.50806	4.08998	4.76494	6.45339	8.71527	11.73708	15.76333	21.11378
33	1.92223	2.25885	2.65234	3.11194	3.64838	4.27403	5.00319	6.84059	9.32534	12.67605	17.18203	23.22515
34	1.96068	2.31532	2.73191	3.22086	3.79432	4.46636	5.25335	7.25103	9.97811	13.69013	18.72841	25.54767
35	1.99989	2.37321	2.81386	3.33359	3.94609	4.66735	5.51602	7.68609	10.67658	14.78534	20.41397	28.10244
36	2.03989	2.43254	2.89828	3.45027	4.10393	4 87738	5.79182	8.14725	11.42394	15.96817	22.25123	30.91268
37	2.08068	2.49335	2.98523	3.57103	4.26809	5.09686	6.08141	8.63609	12.22362	17.24563	24.25384	34.00395
38	2.12230	2.55568	3.07478	3.69601	4.43881	5.32622	6.38548	9.15425	13.07927	18.62528	26.43668	37.40434
39	2.16474	2.61957	3.16703	3.82537	4.61637	5.56590	6.70475	9.70351	13.99482	20.11530	28.81598	41.14478
40	2.20803	2.68506	3.26204	3.95926	4.80102	5.81636	7.03999	10.28572	14.97446	21.72452	31.40942	45.25926
41	2.25220	2.75219	3.35990	4.09783	4.99306	6.07810	7.39199	10.90286	16.02267	23.46248	34.23627	49.78518
42	2.29724	2.82100	3.46070	4.24126	5.19278	6.35161	7.76159	11.55703	17.14426	25.33948	37.31753	54.76370
43	2.34319	2.89152	3.56452	4.38970	5.40050	6.63744	8.14967	12.25045	18.34435	27.36664	40.67611	60.24007
44	2.39005	2.96381	3.67145	4.54334	5.61652	6.93612	8.55715	12.98548	19.62846	29.55597	44.33696	66.26408
45	2.43785	3.03790	3.78160	4.70236	5.84118	7.24825	8.98501	13.76461	21.00245	31.92045	48.32729	72.89048
46	2.48661	3.11385	3.89504	4.86694	6.07482	7.57442	9.43426	14.59049	22.47262	34.47409	52.67674	80.17953
47	2.53634	3.19169	4.01190	5.03782	6.31782	7.91527	9.90597	15.46592	24.04571	37.23201	57.41765	88.19749
48	2.58707	3.27149	4.13225	5.21359	6.57053	8.27145	10.40127	16.39387	25.72891	40.21057	62.58524	97.01723
49	2.63881	3.35328	4.25622	5.39606	6.83335	8.64367	10.92133	17.37750	27.52993	43.42742	68.21791	106.71896
50	2.69159	3.43711	4.38391	5.58493	7.10668	9.03264	11.46740	18.42015	29.45703	46.90161	74.35752	117.39085

PRESENT WORTH

Same as compound discount. Present value of one dollar due at the end of N years.

Years	2%	2½%	3%	3½%	4%	4½%	5%	6%	7%	8%	9%	10%
1	.98039	.97561	.97087	.96618	.96154	.95694	.95238	.94340	.93458	.92593	.91743	.90909
2	.96117	.95181	.94260	.93351	.92456	.91573	.097030	.89000	.87344	.85734	.84168	.82645
3	.94232	.92860	.91514	.90194	.88900	.87630	.86384	.83962	.81630	.79383	.79383	.75131
4	.92385	.90595	.88849	.87144	.85480	.83856	.82270	.79209	.76290	.73503	.70843	.68301
5	.90573	.88385	.86261	.84197	.82193	.80245	.78353	.74726	.71299	.68058	.64993	.62092
6	.88797	.86230	.83748	.81350	.79031	.76790	.74622	.70496	.66634	.63017	.59627	.56447
7	.87056	.84127	.81309	.78599	.75992	.73483	.71068	.66506	.62275	.58349	.54703	.51316
8	.85349	.82075	.78941	.75941	.73069	.70319	.67684	.62741	.58201	.54027	.50187	.46651
9	.83676	.80073	.76642	.73373	.70259	.67290	.64461	.59190	.54393	.50025	.46043	.42410
10	.82035	.78120	.74409	.70892	.67556	.64393	.61391	.55839	.50835	.46319	.42241	.38554
11	.80426	.76214	.72242	.68495	.64958	.61620	.58468	.52679	.47509	.42888	.38753	.35049
12	.78849	.74356	.70138	.66178	.62460	.58966	.55684	.49697	.44401	.39711	.35553	.31863
13	.77303	.72542	.68095	.63940	.60057	.56427	.53032	.46884	.41496	.36770	.32618	.28966
14	.75788	.70773	.66112	.61778	.57748	.53997	.50507	.44230	.38782	.34046	.29925	.26333
15	.74301	.69047	.64186	.59689	.55526	.51672	.48102	.41727	.36245	.31524	.27454	.23939
16	.72845	.67363	.62317	.57671	.53391	.49447	.45811	.39365	.33873	.29189	.25187	.21763
17	.71416	65720	.60502	.55720	.51337	.47318	.43630	.37136	.31657	.27027	.23107	.19784
18	.70016	.64117	.58739	.53836	.49363	.45280	.41552	.35034	.29586	.25025	.21199	.17986
19	.68643	.62553	.57029	.52016	.47464	.43330	.39573	.33051	.27651	.23171	.19449	.16351
20	.67297	.61027	.55368	.50257	.45639	.41464	.37689	.31180	.25842	.21455	.17843	.14864
21	.65978	.59539	.53755	.48557	.43883	.39679	.35894	.29416	.24151	.19866	.16370	.13513
22	.64684	.58086	.52189	.46915	.42196	.37970	.34185	.27751	.22571	.18394	.15018	.12285
23	.63416	.56670	.50669	.45329	.40573	.36335	.32557	.26180	.21095	.17032	.12778	.11168
24	.62172	.55288	.49193	.43796	.39012	.34770	.31007	.24698	.19715	.15770	.12640	.10153
25	.60953	.53939	.47761	.42315	.37512	.33273	.29530	.23300	.18425	.14602	.11597	.09230
26	.59758	.52623	.46369	.40884	.36069	.31840	.28124	.21981	.17220	.13520	.10639	.08391
27	.58586	.51340	.45019	.39501	.34682	.30469	.26785	.20737	.16093	.12519	.09761	.07628
28	.57437	.50088	.43708	.38165	.33348	.29157	.25509	.19563	.15040	.11591	.08955	.06934
29	.56311	.48866	.42435	.36875	.32065	.27901	.24295	.18456	.14056	.10733	.08215	.06304
30	.55207	.47674	.41199	.35628	.30832	.26700	.23138	.17411	.13137	.09938	.07537	.05731
31	.54125	.46511	.39999	.34423	.29646	.25550	.22036	.16425	.12277	.09202	.06915	.05210
32	.53063	.45377	.38834	.33259	.28506	.24450	.20987	.15496	.11474	.08520	.06344	.04736
33	.52023	.44270	.37703	.32134	.27409	.23397	.19987	.14619	.10723	.07889	.05820	.04306
34	.51003	.43191	.36604	.31048	.26355	.22390	.19035	.13791	.10022	.07305	.05339	.03914
35	.50003	.42137	.35538	.29998	.25342	.21425	.18129	.13011	.09366	.06763	.04899	.03558
36	.49022	.41109	.34503	.28983	.24367	.20503	.17266	.12274	.08754	.06262	.06262	.03235
37	.48061	.40107	.33498	.28003	.23430	.19620	.16444	.11579	.08181	.05799	.04123	.02941
38	.47119	.39128	.32523	.27056	.22529	.18775	.15661	.10924	.07646	.05369	.03783	.02673
39	.46195	.38174	.31575	.26141	.21662	.17967	.14915	.10306	.07146	.04971	.03470	.02430
40	.45289	.37243	.30656	.25257	.20829	.17193	.14205	.09722	.06678	.04603	.03184	.02209
41	.44401	.36335	.29763	.24403	.20028	.16453	.13528	.09172	.06241	.04262	.04494	.02009
42	.43530	.35448	.28896	.23578	.19257	.15744	.12884	.08653	.05833	.03946	.02680	.01826
43	.42677	.34584	.28054	.22781	.18517	.15066	.12270	.08163	.05451	.03654	.02458	.01660
44	.41840	.33740	.27237	.22010	.17805	.14417	.11686	.07701	.05095	.03383	.02255	.01509
45	.41020	.32917	.26444	.21266	.17120	.13796	.11130	.07265	.04761	.03133	.02069	.01372
46	.40215	.32115	.25674	.20547	.16461	.13202	.10600	.06854	.04450	.02901	.01898	.01247
47	.39427	.31331	.24926	.19852	.15828	.12634	.10095	.06466	.04159	.02686	.01742	.01134
48	.38654	.30567	.24200	.19181	.15219	.12090	.09614	.06100	.03887	.02487	.01598	.01031
49	.37896	.29822	.23495	.18532	.14634	.11569	.09156	.05755	.03632	.02303	.01466	.00937
50	.37153	.29094	.22811	.17905	.14071	.11071	.08720	.05429	.03395	.02132	.01345	.00852

Unaccounted-For Gas:

Where it goes and how to prevent such losses

UNACCOUNTED-for gas is generally thought of in terms of leakage losses in the underground distribution system. This, however, accounts for only a portion of the gas losses. To disregard the other contributing factors only penalizes the underground structure.

How much of the unaccounted-for gas may be ascribed to actual leakage and how much may be ascribed to other factors depends upon the condition of the distribution system and upon the conditions contributing to the losses due to other causes. Unaccounted-for gas is an unavoidable evil, but while it may be unavoidable, it certainly can be minimized.

Escaping gas is a potential danger and any reduction in the amount of unaccounted-for gas, from any cause whatever, creates not only a monetary saving but is also a source of additional revenue.

Each company has adopted some arbitrary standard by which to judge the condition of a system. Is this standard serving as well today with new huge space heating and industrial loads as it did when first adopted?

The problem of unaccounted-for gas is a serious one, not only because of the high cost of the gas and from the angle of public safety, but there is also the problem of maintenance.

The amount of money spent in the past and that is continuing to be spent needlessly even today, through misdirected maintenance efforts, cannot be calculated. Were more facts made available, the maintenance efforts could be made much more effective.

$100,000,000 Annual Loss

In recent years the quantities of unaccounted-for gas have reached astronomical proportions and each cubic foot of it must be bought and paid for. With the increasing costs of gas, the prices paid for such losses are staggering.

Gas sales to ultimate consumers by utilities and pipe lines were recently reported as 6,696,470,000 Mcf. A 50 per cent average unaccounted-for figure is considered conservative. This results in an estimated 334,823,500 Mcf of unaccounted-for gas, which, if purchased at an average price of 30 cents per Mcf, amounts to $103,795,300 a year. This is a recurring cost and it might be well to determine what contributes to this annual waste.

No comprehensive study of unaccounted-for gas has been made and presented before the American Gas Association since 1911, when J. D. von Maur made a study of the causes of unaccounted-for gas. Von Maur's list of 26 items may be boiled down to perhaps 9 basic items. Some of these items are no longer applicable, but in their stead other sources of unaccounted-for

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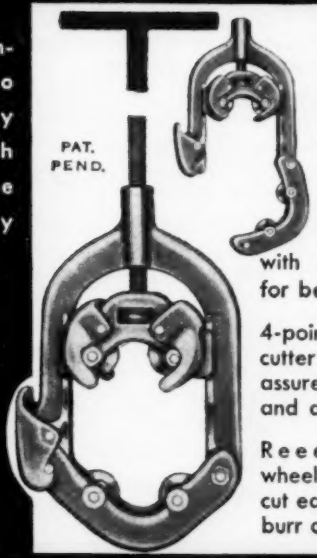

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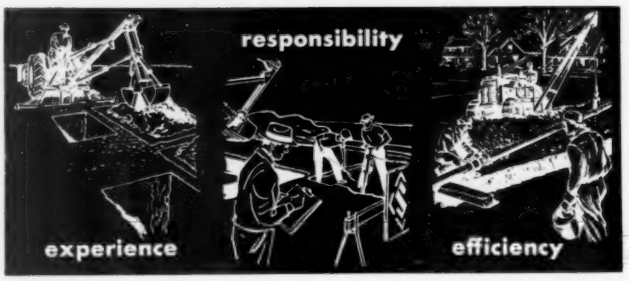

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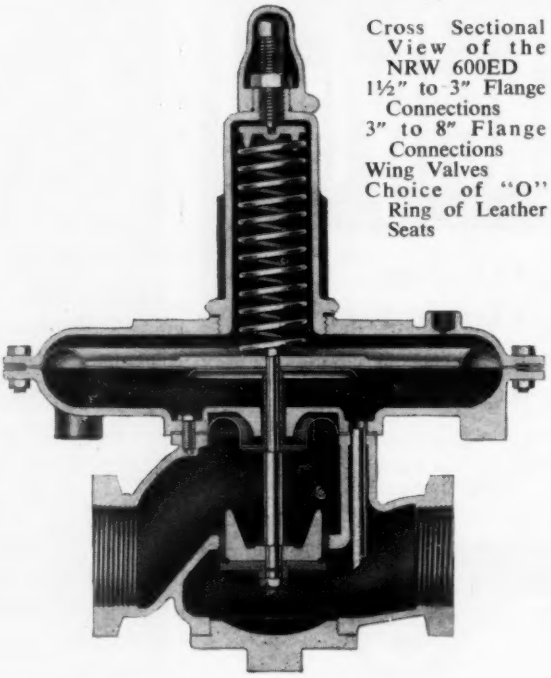

Cross Sectional View of the NRW 600ED
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gas have come into existence.

Recognition of these hidden losses, their magnitude and their cost to the industry can help operating men and management plan and channel efforts to reduce the unaccounted-for gas and determine the extent of maintenance programs along such channels. Properly conceived, economic and safety studies can be of great value in directing maintenance efforts.

Task Group Studies Problem

A task group consisting of J. H. Glamser, Oklahoma Natural Gas Company, J. S. Janssen, New Orleans Public Service Company, and L. C. Rohret, Middle West Service Company, has been investigating the factors contributing to unaccounted-for gas and evaluating these factors.

The material being presented here represents only a light sampling and the figures quoted are in no way conclusive. Each system, each city, each town and even an area presents its own problem and this study can only point out the need for a local study, and support the objectives to be accomplished.

The material upon which this article is based was obtained through a questionnaire submitted to a group whom it was felt were in a position to supply the more detailed information. While all of the questionnaires were not returned, a sufficient number were returned to establish certain patterns that supply much food for thought. It has been recognized that local conditions affect the intensity of the pattern for any particular situation or for any individual company. Consideration must be given to this fact in applying these remarks to individual situations.

The Problem:

Unaccounted-for gas may be considered that portion of the gas purchased or manufactured that is not accounted for by sales, transfer, company use, or other uses.

Most companies report unaccounted-for gas in cubic feet, and as a percentage of the sendout. This provides a very elastic yardstick with which to judge the condition of a distribution system. For example —a manufactured gas system with a 5 per cent unaccounted-for figure converts to natural gas and the sendout increases tenfold.

If a 5 per cent unaccounted-for figure is maintained, the quantity of unaccounted-for gas will be 10 times as great for practically the same system. Fortunately, all this increase is not leakage or we might find ourselves unable to live with it.

How Reported?

Some companies report their unac-

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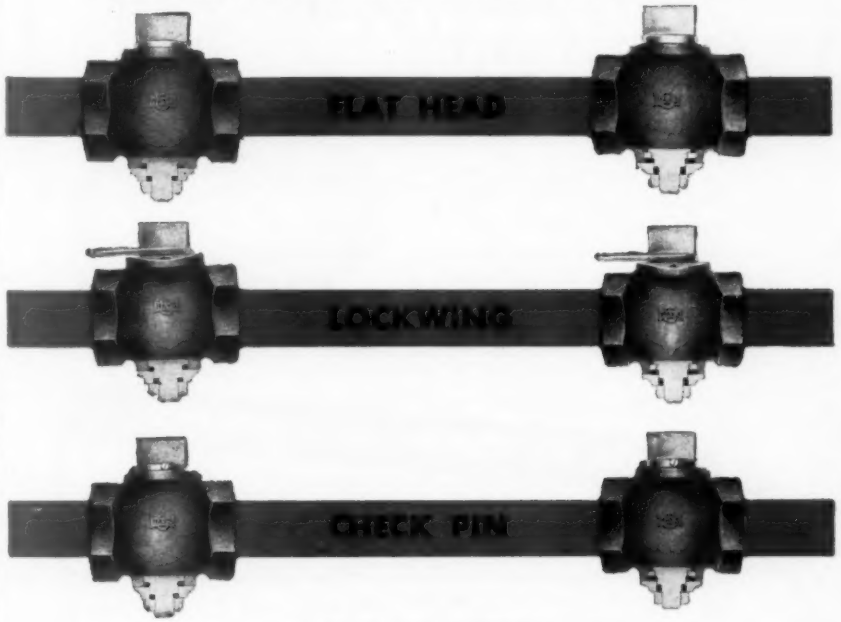

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counted-for gas in cubic feet per 3-in. equivalent mile of main. At one time when gas sales were relatively small this was a more realistic method of reporting unaccounted-for gas than reporting a percentage of the total send-out. Changing conditions due to large average gas sales have altered this situation.

Reporting unaccounted-for gas as a percentage tends to minimize the seriousness of large quantities of unaccounted-for gas and reporting it in cubic feet per 3-in. equivalent mile can make the distribution system look worse than it really is. Somewhere in between lies the correct answer.

Reporting the portion of gas due to causes other than leakage on a per meter basis, reporting the portion due to main leakage on a 3-in. main equivalent basis, and the portion due to service leakage on a 3-in. equivalent basis, might present a more realistic picture.

At the present time, probably no company keeps records that differentiate the losses due to the different factors contributing to the unaccounted-for gas. For the purpose of approximating these losses, a different approach to the problem must be devised.

Standards Needed

Before intelligently considering the factors affecting unaccounted-for gas, everything must be reduced to the same standard. It is impossible to evaluate any factor by using two standards of measurement. At present there are two yardsticks with which to measure the gas: correct the gas to a 60-deg, 30-in. base to report the sendout, or meter the gas at the existing atmospheric temperature pressure to report the sales.

The method of metering gas at the consumers' premises cannot be changed. In order to account for every cubic foot of gas volume sent out, the sendout must be reduced to the same basis.

The reason for this is quite obvious when we realize that companies operating at high altitudes may show a negative unaccounted-for every month.

For the purpose of uniformity in pipe line billing and for determining the operating efficiencies of a manufactured gas plant the gas should be corrected to some set standard. The temperature-pressure standard for manufactured gas is usually 60 F and 30-in. Hg. pressure. In calculating the amount of gas delivered to a distributing company by a pipe line company some arbitrary pressure is adopted.

A review of a number of pipe line tariffs at hand shows them all to be corrected to 60 F but the pressure bases vary as follows:

30-in. Hg.
14.65 lb abs.
14.73 lb abs.
14.90 lb abs.
15.025 lb abs.

No change in the present method of reporting the unaccounted-for gas, or any change in the method of calculating it is suggested. The present method serves a purpose and appears to serve it adequately. The present method of reporting sendout, however, is misleading if used as a guide in studying the unaccounted-for problem.

Unaccounted-for gas studies, however, should have a method that will determine the actual difference between the actual volume of gas leaving the plant and the actual volume metered at the customers' premises.

Formulas are available that will permit calculating the actual volume of dry gas being sent out from the plant for different temperatures, delivery pressures and elevations. Charts with a limited range are available and may be used as a basis for calculating the volume of saturated gas. Where daily station meter readings are available, a more accurate figure may be obtained by applying the correction for the daily barometric reading.

Once the actual volume of unaccounted-for gas is obtained, the next step is to determine where it is going and in what quantities. After making such an analysis it is possible to determine where maintenance time and money may be spent to the greatest advantage.

Making More Exact Studies

Suppose meter shop tests show a company's meters to average 2 per cent slow. Obviously, then, the loss due to slow meters is 2 per cent of the annual sales, which loss we shall call X-Mcf. For the mythical company we show a 5 per cent unaccounted-for loss, which means that 40 per cent of the unaccounted-for can be charged to slow meters.

In our analysis we find that the correction for true barometric pressure adds 3 per cent to the gas sendout. This would result in a total unaccounted-for of 8 per cent, but the quantity of gas unaccounted-for due to slow meters would remain unchanged. The percentage of the total unaccounted-for gas chargeable to slow meters then becomes 25 per cent.

Losses at the residential customers' meters	**20.6%**
Losses at commercial customers' meters	**1.7**
Theft	**.7**
Main Leakage	**39.8**
Service Leakage	**16.0**
Other Losses	**21.0**
	100.0

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The difficulty in separating two types of unaccounted-for gas becomes a problem. Perhaps we may never develop a technique that is perfect, but thought, experience and ingenuity can develop methods that will be better than ignoring the situation entirely as is done today.

What Can Be Done?

The following thoughts are being presented to stimulate thinking toward devising methods of determining the actual quantity of unaccounted-for gas and by the process of elimination and judgment arrive at a reasonable approximation of the amount of loss due to the different factors contributing to such loss.

As stated before, the method of metering gas at the customers' premises cannot be changed, so that must be the basis for all unaccounted-for studies. The proper factor should be first applied to the purchased or manufactured gas to bring it to the same basis as the gas sold. The most accurate means is to apply daily ground temperature and barometric factor to the daily sendout. Allowance must be made for the metering pressure of the gas. This will give the actual volumetric quantity of gas sent out. Further refinements may be made, but too much refinement is probably impractical.

It is convenient to make a list of all the causes of unaccounted-for gas and as the amount of unaccounted-for is estimated enter it opposite the proper classification.

By correcting for elevation or, more accurately, to actual barometric pressure, the errors due to the use of an arbitrary barometric-temperature correction are eliminated.

Unaccounted-for gas due to a *temporary rising of the delivery pressure* above the standard delivery pressure can be calculated from the quantity of gas delivered at the increased pressure.

Unaccounted-for gas due to *gas theft* is usually a small item and can be estimated quite readily.

Unaccounted-for gas due to *slow meters* can be estimated very closely by a study of the meter shop test records.

Unaccounted-for gas due to *D. R. Meters* is more difficult to estimate, particularly if the meter has been in service for any appreciable length of time before discovery.

Unaccounted-for gas due to *failure of meter to register pilot flow* in service. This loss is higher than is generally realized as many meters that are apparently registering this flow are actually measuring only a portion of it.

Unaccounted-for gas due to *main leakage* and to *service leakage* is virtually impossible to estimate by ordinary

means. It is best obtained by eliminating the estimated unaccounted-for due to all other causes and assume that the remainder is leakage. The portion of leakage ascribed to mains and the portion ascribed to services should be based upon judgment and should reflect the number and size of leaks repaired in mains as against the number and size of leaks repaired in services. Some operators require the estimated rate of leakage to be recorded upon the main or service repair order.

The factors affecting unaccounted-for gas just mentioned are the ones most commonly recognized. Generally speaking, the unaccounted-for gas due to any single one of the other contributing factors is relatively small; however, in the aggregate they may present a very sizeable figure.

Other Loss Causes

The losses due to other causes include:

Lost meters. Much ingenuity will be necessary to eliminate from the gas meters unaccounted-for, the condemned meters with lost or confusing records, meters destroyed by fire, those destroyed or lost during the demolition of a building and those carried along with the household goods when the tenants moved. The meters remaining may be considered lost until it can be determined what disposition was made of them. Too frequently some of these will be found set in some forgotten location without having been read in years.

Wrong index on meters. This error is not frequent but it does occur.

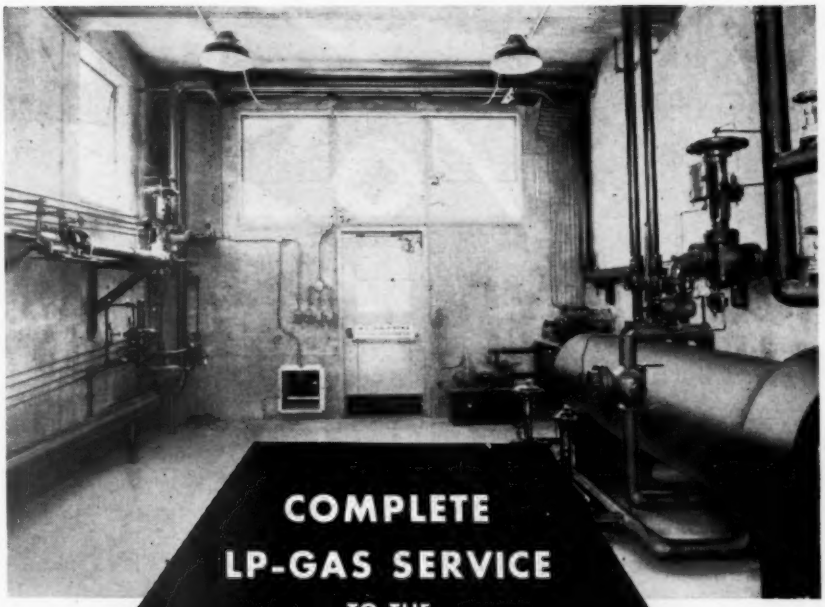
Service men increase delivery pressure at the customer's governor to give the customer adequate service. This is a very frequent occurrence and results in a substantial loss in meter registration.

Gas lost in purging mains and in making main connections and gas lost in purging services and in making service connections. The gas lost in these two activities may or may not be substantial but large or small they still contribute to the unaccounted-for gas.

Street lighting system losses remain with only a few companies so they are not a general problem.

Oil or water condensate in the distribution system. Such condensate results in unaccounted-for only if it has been metered while in the form of vapor.

Incorrect station meter or wrong correction factors used. The type, the design and the size of meter all have



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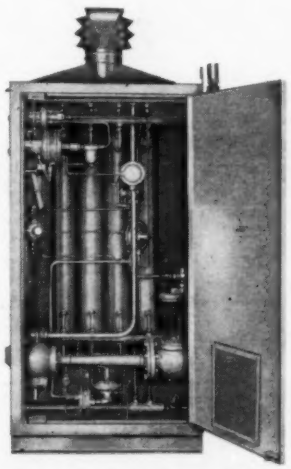

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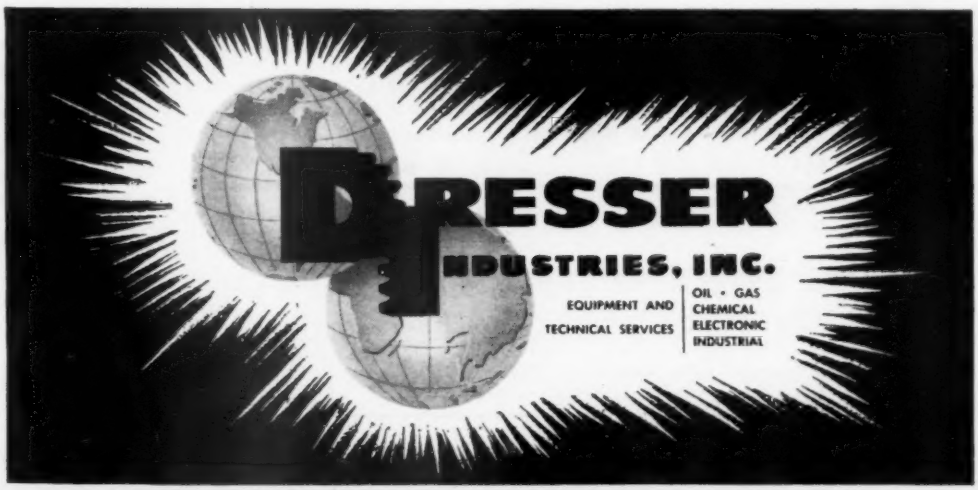

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a bearing, as each meter has its own characteristics that must be recognized and taken into consideration.

Interconnections between systems. Such interconnections present many kinds of problems and consideration should be given to such conditions to determine if they are contributing to the unaccounted-for.

Unmetered company use. This is a very common condition and can result in a very substantial figure.

Too high pressures on the distribution system. This is a very common condition and is a substantial contributor to the unaccounted-for gas.

Leakage in customer's regulators. Such leaks are easy to repair but they are not easy to detect. Substantial leaks can develop in some regulator installations and can exist for a long time before being discovered.

The factors enumerated in this miscellaneous list are not present in all systems and some companies may have factors that have not been included.

Classification of Causes

While a detailed consideration of all factors contributing to unaccounted-for gas is necessary in order to identify and evaluate the causes, for ordinary consideration they may be placed in three general classifications: **Main Leakage, Service Leakage, and Causes Other Than Leakage.**

Some companies are fortunate enough to have constructed entirely new gas systems in towns or cities that did not have gas before. Such distribution systems are well built and have withstood severe pressure and leakage tests and are as nearly bottle tight as it is possible to make them. These companies have an excellent opportunity to check the amount of unaccounted-for gas due to causes other than leakage.

It is reasonably safe to assume that no material leakage will develop over the first several years. Any unaccounted-for gas that develops may be ascribed to causes other than main or service leakage. A correction should be applied to compensate for the meter reading lag where the load is changing rapidly. The longer the test period, the less influence the meter lag will have upon the test figures.

If enough of these tests and the surrounding conditions can be made available, the results will supply a firm basis for a more detailed study.

Acknowledgment

This discussion was presented by L. C. Rohret, Middle West Service Company, Chicago, Illinois, at the annual AGA Distribution, Motor Vehicles, and Corrosion Conference, Chicago, 1956.

* * *

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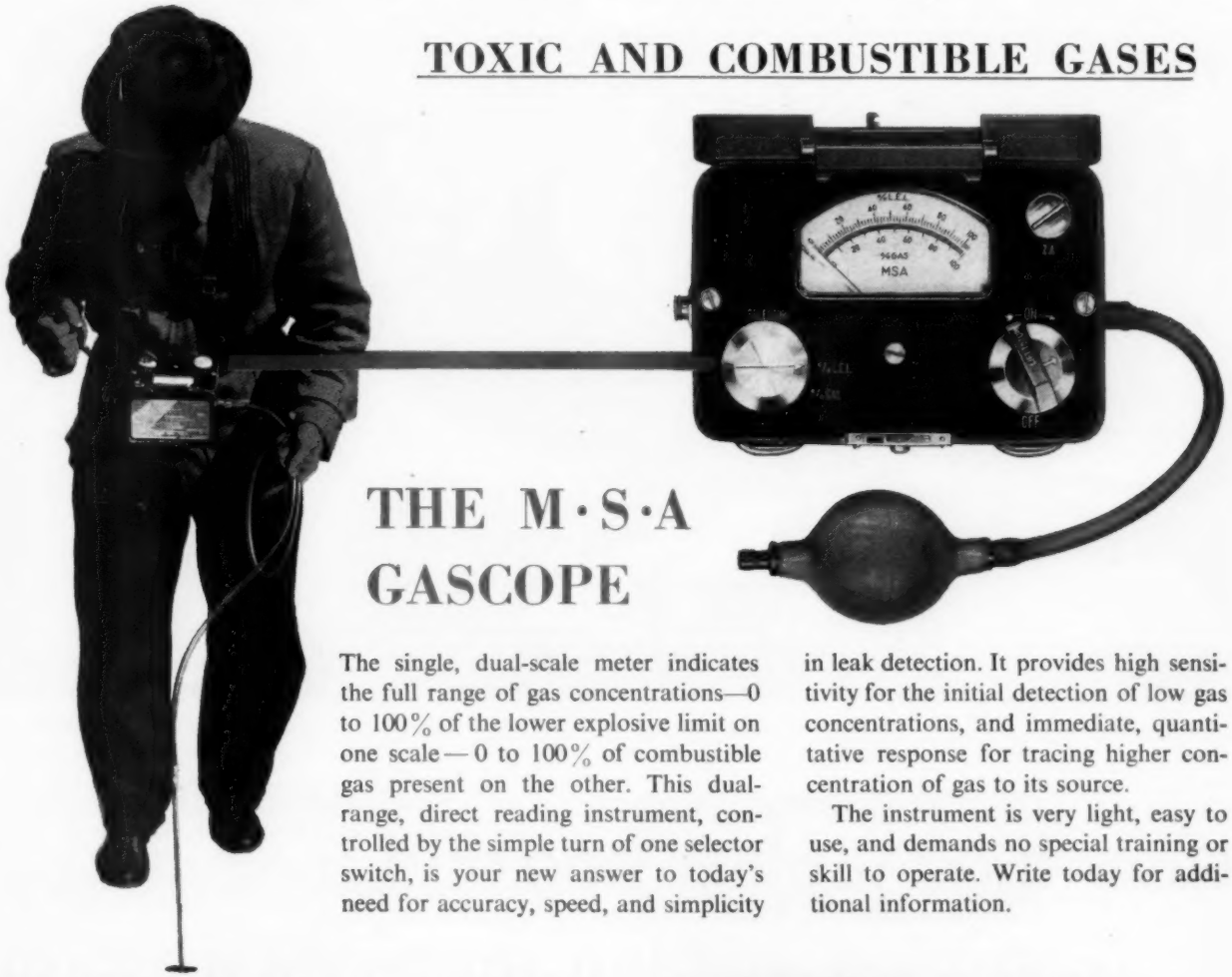

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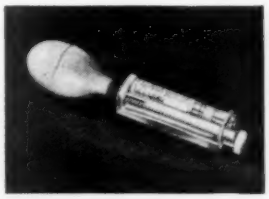

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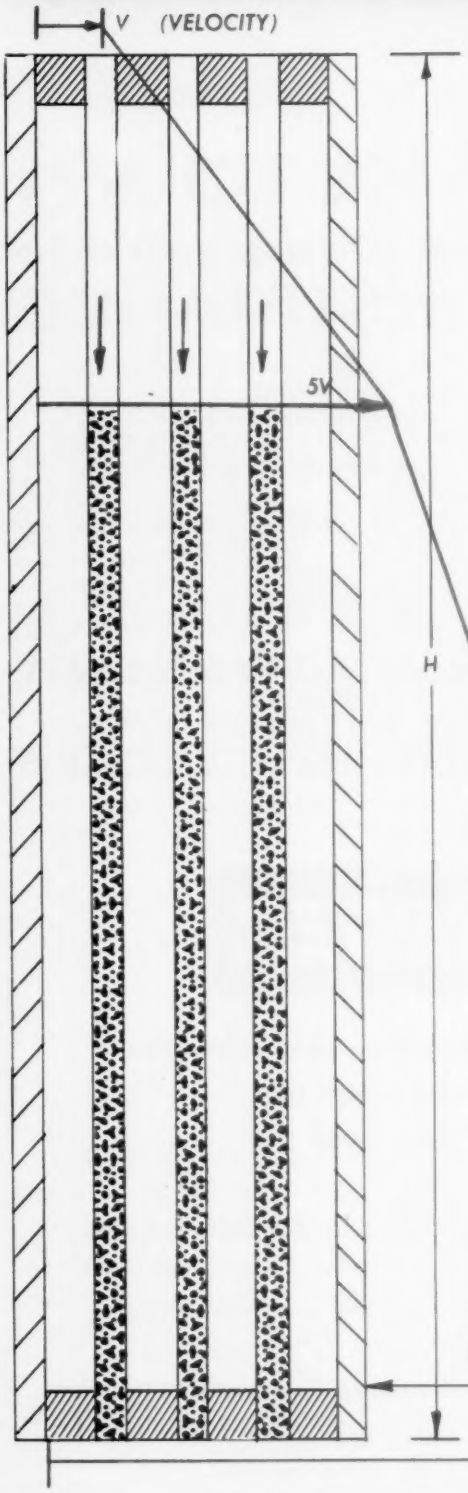

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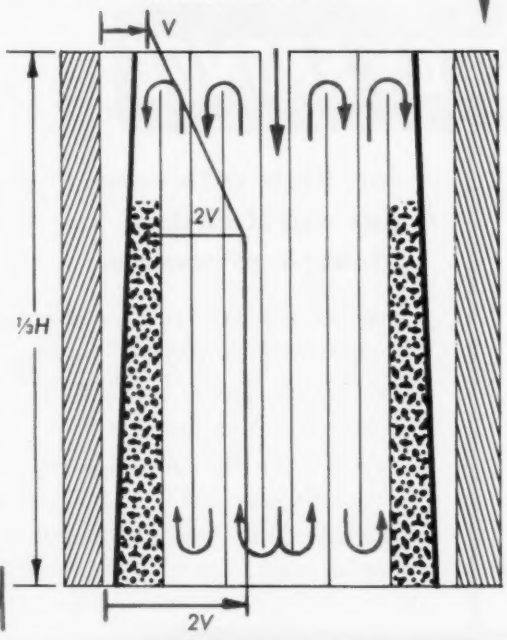

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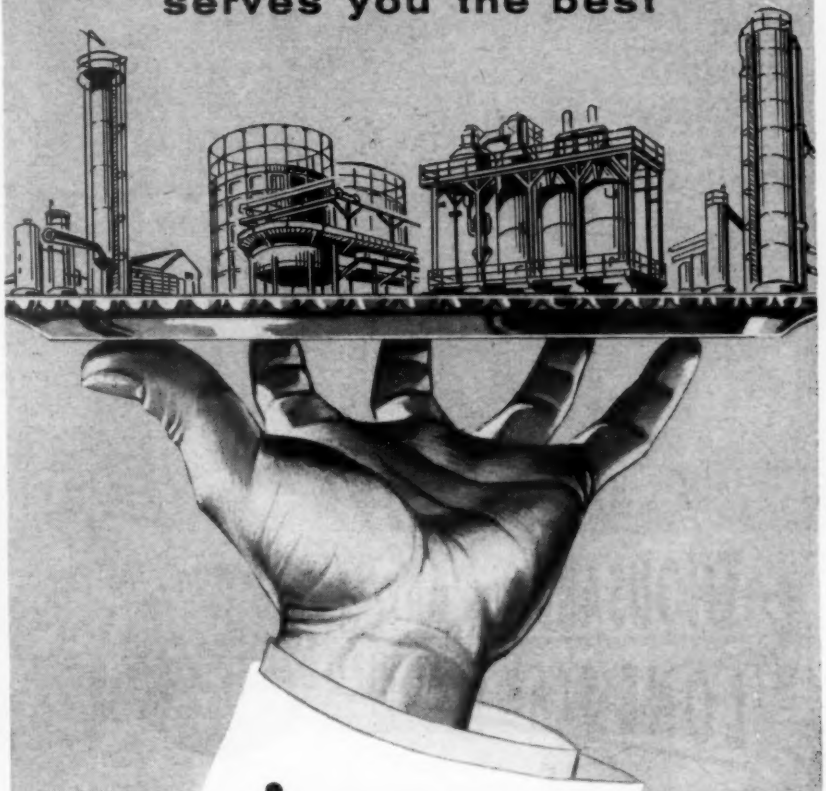

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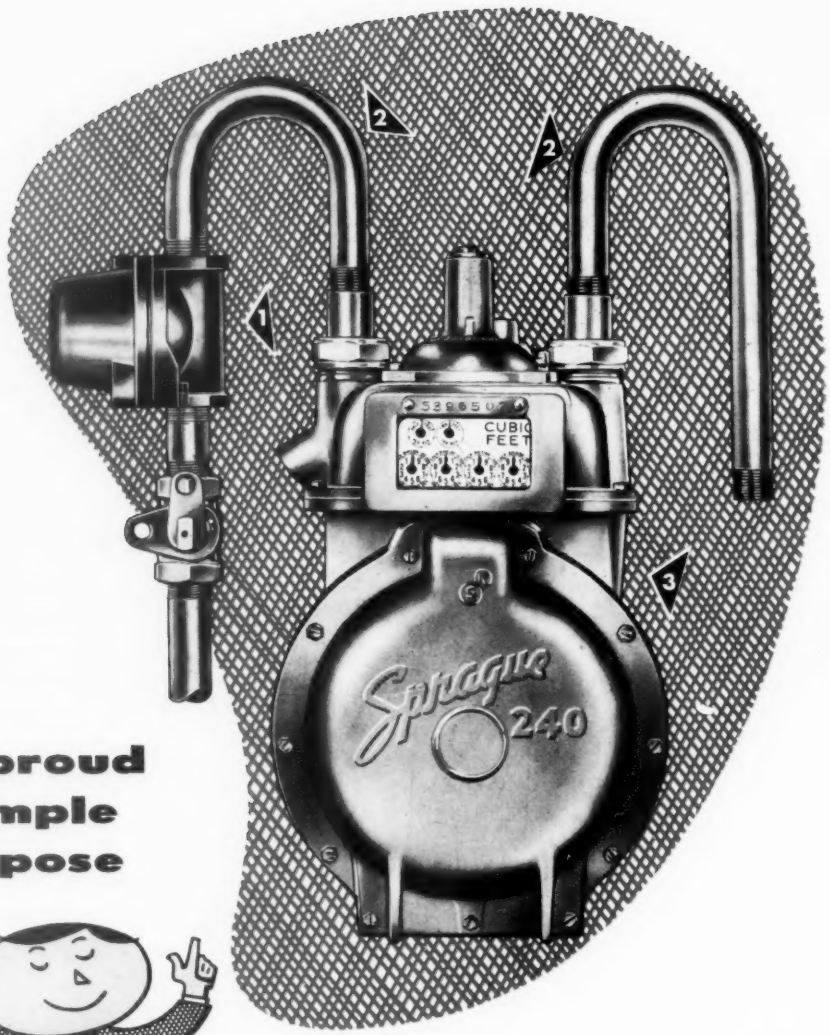

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